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UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA
SAN FRANCISCO DIVISION

AuthenTec, Inc., a Delaware corporation,

Plaintiff,

VS.

Atrua Technologies, Inc., a California corporation,

Defendant.

Case No. C 08-1423 PJH

**STIPULATION AND [PROPOSED] ORDER
FOR FILING OF AUTHENTEC, INC.'S
SECOND AMENDED COMPLAINT FOR
PATENT INFRINGEMENT, FALSE
ADVERTISING, INTERFERENCE WITH
PROSPECTIVE ECONOMIC
ADVANTAGE, AND TRADE LIBEL**

Judge: Hon. Phyllis J. Hamilton

AND RELATED COUNTERCLAIMS

1 Pursuant to Federal Rule of Civil Procedure 15(a)(2),
 2
 3

4 IT IS HEREBY STIPULATED by and between Plaintiff AuthenTec, Inc., ("AuthenTec") and
 5 Defendant Atrua Technologies, Inc. ("Atrua"), by and through their respective undersigned counsel of
 6 record, that AuthenTec may file with the Court its Second Amended Complaint For Patent
 7 Infringement, Unfair Competition, False Advertising, Interference With Prospective Economic
 8 Advantage, And Trade Libel ("Second Amended Complaint"), a copy of which is attached. Defendant
 9 Atrua acknowledges service of a copy of AuthenTec's Second Amended Complaint via the present
 10 stipulation. The parties further stipulate and agree that Atrua will have twenty (20) days time from
 11 today's date to provide an answer to AuthenTec's Second Amended Complaint.

10 IT IS SO STIPULATED.

11 Dated: July 30, 2008

12 HOWREY LLP

13
 14 By: _____ */s/Denise M. De Mory*
 15 Denise M. De Mory
 16 Attorneys for Plaintiff
 17 AUTHENTEC, INC.

18 Dated: July 30, 2008

19 GREENBERG TAURIG, LLP

20 By: _____ */s/J. James Li*
 21 J. James Li
 22 Attorneys for Defendant
 23 ATRUA TECHNOLOGIES, INC.

24 PURSUANT TO STIPULATION, IT IS SO ORDERED.

25 Dated: July ____, 2008

26 _____ Hon. Phyllis J. Hamilton
 27 Judge, United States District Court

CERTIFICATION BY DENISE M. DE MORY PURSUANT TO GENERAL RULE NO. 45,

SECTION X. RE E-FILING ON BEHALF OF MULTIPLE SIGNATORIES

3 1. I am an attorney licensed to practice law in the state of California, and am a partner in
4 the law firm of Howrey LLP, counsel for plaintiff AuthenTec, Inc. The statements herein are made on
5 my personal knowledge, and if called as a witness I could and would testify thereto.

6 2. The above e-filed document contains multiple signatures. I declare that concurrence
7 has been obtained from each of the other signatories to file this jointly prepared document with the
8 Court. Pursuant to General Rule No. 45, I shall maintain records to support this concurrence for
9 subsequent production for the Court if so ordered, or for inspection upon request by a party until one
10 year after final resolution of the action (including appeal, if any).

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct on July 30, 2008.

/s/Denise M. De Mory
Denise M. De Mory

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10 | Attorneys for Plaintiff AuthenTec, Inc.

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA
SAN FRANCISCO DIVISION

15 | AuthenTec, Inc., a Delaware corporation,

Case No. C08-01423 PJH

Plaintiff,

VS.

18 Atrua Technologies, Inc., a California corporation,

Defendant.

**SECOND AMENDED COMPLAINT FOR
PATENT INFRINGEMENT, UNFAIR
COMPETITION, FALSE ADVERTISING,
INTERFERENCE WITH PROSPECTIVE
ECONOMIC ADVANTAGE, AND TRADE
LIBEL**

DEMAND FOR JURY TRIAL

22 Plaintiff AuthenTec, Inc. (“AuthenTec”) alleges the following in support of its Second
23 Amended Complaint for Patent Infringement and Demand for Jury Trial (“Second Amended
24 Complaint”) against Defendant Atrua Technologies, Inc. (“Atrua”):

PARTIES

26 1. AuthenTec is a Delaware corporation having a principal place of business at 709 South
27 Harbor City Boulevard, Melbourne, Florida 32901.

2. On information and belief, Atrua is a California corporation having a principal place of business at 1696 Dell Avenue, Campbell, California 95008.

JURISDICTION

3. This action arises under violations of federal patent law, the Lanham Act (15 U.S.C. §§ 1051-1127 *et seq.*), California statutory unfair competition law (Cal. Bus. & Prof. Code §§ 17200 and 17500), and the California common law doctrines of unfair competition, intentional interference with prospective economic advantage, and trade libel. Accordingly, this Court has subject matter jurisdiction pursuant to 28 U.S.C. §§ 1331, 1338, and 1367. This Court has subject matter jurisdiction over the patent claims in this action pursuant to 28 U.S.C. §§ 1331, 1338(a) because this action arises under the patent laws of the United States, including 35 U.S.C. §§ 101, *et seq.* and 271, *et seq.* This Court has subject matter jurisdiction over AuthenTec's declaratory judgment claim under the Federal Declaratory Judgment Act, 28 U.S.C. § 2201, *et seq.*, and 28 U.S.C. § 1338(a). This Court has subject matter jurisdiction over the Lanham Act claims pursuant to 28 U.S.C. § 1331. This Court has jurisdiction over the California state law claims pursuant to 28 U.S.C. §§ 1338 and 1367.

4. This Court has personal jurisdiction over Atrua because AuthenTec is informed and believes that Atrua is incorporated in California and maintains its corporate headquarters in Campbell, California, which is located in this District. As such, Atrua has transacted business in this District, contracted to supply goods or services in this District, and purposefully availed itself of the privileges and benefits of the laws of the State of California. This Court also has jurisdiction over Atrua because it has committed violations of federal patent law, the Lanham Act, and California law during the course of its business in this District.

VENUE

5. Venue is proper in this judicial District under 28 U.S.C. §§ 1391(b) and 1400(b) because AuthenTec is informed and believes that a substantial part of the events giving rise to this claim occurred in this District, and Atrua has a regular and established place of business in this District.

INTRADISTRICT ASSIGNMENT

6. This action is an Intellectual Property Action that arises in Santa Clara County.

Pursuant to Civil L.R. 3-2(c) and (e), this action should be assigned to the San Jose Division.

COUNT 1

(Infringement of U.S. Patent No. 5,862,248)

7. Paragraphs 1 through 6 of the Second Amended Complaint set forth above are incorporated herein by reference.

8 8. On January 19, 1999, United States Patent No. 5,862,248 ("the '248 Patent") entitled
9 "Integrated Circuit Device Having an Opening Exposing the Integrated Circuit Die and Related
10 Methods" was duly and legally issued to Matthew M. Salatino, S. James Studebaker, and Nicolaas W.
11 VanVonno. AuthenTec is the owner of all rights and interest in and to the '248 Patent by assignment.
12 A true and correct copy of the '248 Patent is attached hereto as Exhibit A.

13 9. Upon information and belief, Atrua has infringed and continues to infringe under 35
14 U.S.C. § 271 the ‘248 Patent. The infringing acts include, but are not limited to, importing, selling,
15 and offering for sale in the United States biometric products, systems, and devices, including
16 fingerprint sensors, that are covered by one or more claims of the ‘248 Patent, and inducing and
17 contributing to the infringement of such claims. Atrua has been offering and continues to offer for sale
18 such products, systems, and devices without the authorization of AuthenTec.

19 10. Atrua's acts of infringement have caused damage to AuthenTec in an amount subject to
20 proof at trial. Under 35 U.S.C. § 284, AuthenTec is entitled to recover from Atrua the damages
21 sustained by AuthenTec as a result of Atrua's infringement of the '248 Patent. Atrua's infringement of
22 AuthenTec's exclusive rights under the '248 Patent will continue to damage AuthenTec's business,
23 causing it irreparable harm, for which there is no adequate remedy at law, unless enjoined by this
24 Court under 35 U.S.C. § 283.

25 11. Upon information and belief, Atrua's infringement of the '248 Patent has been willful
26 and deliberate, and entitles AuthenTec to increased damages under 35 U.S.C. § 284 and attorneys' fees
27 and costs under 35 U.S.C. § 285.

COUNT 2**(Infringement of U.S. Patent No. 6,667,439)**

12. Paragraphs 1 through 11 of the Second Amended Complaint set forth above are
incorporated herein by reference.

13. On December 23, 2003, United States Patent No. 6,667,439 ("the '439 Patent") entitled
"Integrated Circuit Package Including Opening Exposing Portion of an IC" was duly and legally issued
to Matthew M. Salatino and Patrick O. Weber. AuthenTec and Hestia Technologies, Inc. are the
owners of all rights and interest in and to the '439 Patent by assignment. A true and correct copy of
the '439 Patent is attached hereto as Exhibit B.

14. Upon information and belief, Atrua has infringed and continues to infringe under 35
U.S.C. § 271 the '439 Patent. The infringing acts include, but are not limited to, importing, selling,
and offering for sale in the United States biometric products, systems, and devices, including
fingerprint sensors, that are covered by one or more claims of the '439 Patent, and inducing and
contributing to the infringement of such claims. Atrua has been offering and continues to offer for sale
such products, systems, and devices without the authorization of AuthenTec.

15. Atrua's acts of infringement have caused damage to AuthenTec in an amount subject to
proof at trial. Under 35 U.S.C. § 284, AuthenTec is entitled to recover from Atrua the damages
sustained by AuthenTec as a result of Atrua's infringement of the '439 Patent. Atrua's infringement of
AuthenTec's exclusive rights under the '439 Patent will continue to damage AuthenTec's business,
causing it irreparable harm, for which there is no adequate remedy at law, unless enjoined by this
Court under 35 U.S.C. § 283.

16. Upon information and belief, Atrua's infringement of the '439 Patent has been willful
and deliberate, and entitles AuthenTec to increased damages under 35 U.S.C. § 284 and attorneys' fees
and costs under 35 U.S.C. § 285.

COUNT 3**(Infringement of U.S. Patent No. 5,940,526)**

17. Paragraphs 1 through 16 of the Second Amended Complaint set forth above are
incorporated herein by reference.

18. On August 17, 1999, United States Patent No. 5,940,526 ("the '526 Patent") entitled
"Electric Field Fingerprint Sensor Having Enhanced Features and Related Methods" was duly and
legally issued to Dale R. Setlak, Nicolaas W. VanVonno, Rex Lowther, and Dave Gebauer.
AuthenTec is the owner of all rights and interest in and to the '526 Patent by assignment. A true and
correct copy of the '526 Patent is attached hereto as Exhibit C

19. Upon information and belief, Atrua has infringed and continues to infringe under 35
U.S.C. § 271 the '526 Patent. The infringing acts include, but are not limited to, importing, selling,
and offering for sale in the United States biometric products, systems, and devices, including
fingerprint sensors, that are covered by one or more claims of the '526 Patent, and inducing and
contributing to the infringement of such claims. Atrua has been offering and continues to offer for sale
such products, systems, devices, processes, and methods without the authorization of AuthenTec.

20. Atrua's acts of infringement have caused damage to AuthenTec in an amount subject to
proof at trial. Under 35 U.S.C. § 284, AuthenTec is entitled to recover from Atrua the damages
sustained by AuthenTec as a result of Atrua's infringement of the '526 Patent. Atrua's infringement of
AuthenTec's exclusive rights under the '526 Patent will continue to damage AuthenTec's business,
causing it irreparable harm, for which there is no adequate remedy at law, unless enjoined by this
Court under 35 U.S.C. § 283.

21. Upon information and belief, Atrua's infringement of the '526 Patent has been willful
and deliberate, and entitles AuthenTec to increased damages under 35 U.S.C. § 284 and attorneys' fees
and costs under 35 U.S.C. § 285.

COUNT 4**(Infringement of U.S. Patent No. 5,963,679)**

22. Paragraphs 1 through 21 of the Second Amended Complaint set forth above are incorporated herein by reference.

23. On October 5, 1999, United States Patent No. 5,963,679 ("the '679 Patent") entitled "Electric Field Fingerprint Sensor Apparatus and Related Methods" was duly and legally issued to Dale R. Setlak. AuthenTec is the owner of all rights and interest in and to the '679 Patent by assignment. A true and correct copy of the '679 Patent is attached hereto as Exhibit D.

24. Upon information and belief, Atrua has infringed and continues to infringe under 35 U.S.C. § 271 the '679 Patent. The infringing acts include, but are not limited to, importing, selling, and offering for sale in the United States biometric products, systems, and devices, including fingerprint sensors, that are covered by one or more claims of the '679 Patent, and inducing and contributing to the infringement of such claims. Atrua has been offering and continues to offer for sale such products, systems, and devices without the authorization of AuthenTec.

25. Atrua's acts of infringement have caused damage to AuthenTec in an amount subject to proof at trial. Under 35 U.S.C. § 284, AuthenTec is entitled to recover from Atrua the damages sustained by AuthenTec as a result of Atrua's infringement of the '679 Patent. Atrua's infringement of AuthenTec's exclusive rights under the '679 Patent will continue to damage AuthenTec's business, causing it irreparable harm, for which there is no adequate remedy at law, unless enjoined by this Court under 35 U.S.C. § 283.

26. Upon information and belief, Atrua's infringement of the '679 Patent has been willful and deliberate, and entitles AuthenTec to increased damages under 35 U.S.C. § 284 and attorneys' fees and costs under 35 U.S.C. § 285.

COUNT 5**(Infringement of U.S. Patent No. 6,259,804)**

27. Paragraphs 1 through 26 of the Second Amended Complaint set forth above are incorporated herein by reference.

1 28. On July 10, 2001, United States Patent No. 6,259,804 (“the ‘804 Patent”) entitled
2 “Fingerprint Sensor with Gain Control Features and Associated Methods” was duly and legally issued
3 to Dale R. Setlak, John Cornett, Brian Kilgore, Daryl Williams, and Dave Gebauer. AuthenTec is the
4 owner of all rights and interest in the ‘804 Patent by assignment. A true and correct copy of the ‘804
5 Patent is attached hereto as Exhibit E.

6 29. Upon information and belief, Atrua has infringed and continues to infringe under 35
7 U.S.C. § 271 the ‘804 Patent. The infringing acts include, but are not limited to, importing, selling,
8 and offering for sale in the United States biometric products, systems, and devices, including
9 fingerprint sensors, that are covered by one or more claims of the ‘804 Patent, and inducing and
10 contributing to the infringement of such claims. Atrua has been offering and continues to offer for sale
11 such products, systems, and devices without the authorization of AuthenTec.

12 30. Atrua's acts of infringement have caused damage to AuthenTec in an amount subject to
13 proof at trial. Under 35 U.S.C. § 284, AuthenTec is entitled to recover from Atrua the damages
14 sustained by AuthenTec as a result of Atrua's infringement of the '804 Patent. Atrua's infringement of
15 AuthenTec's exclusive rights under the '804 Patent will continue to damage AuthenTec's business,
16 causing it irreparable harm, for which there is no adequate remedy at law, unless enjoined by this
17 Court under 35 U.S.C. § 283.

18 31. Upon information and belief, Atrua's infringement of the '804 Patent has been willful
19 and deliberate, and entitles AuthenTec to increased damages under 35 U.S.C. § 284 and attorneys' fees
20 and costs under 35 U.S.C. § 285.

COUNT 6

(Federal Unfair Competition – Lanham Act § 43(a); 15 U.S.C. § 1125(a))

32. Paragraphs 1 through 31 of the Second Amended Complaint set forth above are
incorporated herein by reference.

25 33. Atrua's statements about Atrua's products, AuthenTec, and AuthenTec's products,
26 made in connection with Atrua's goods or services, falsely and misleadingly describes or represents
27 Atrua's products, AuthenTec, and AuthenTec's products. These statements include, but are not limited

1 to, that Atrua advertises on its website that its Wings™ Fingerprint sensor products are “Compliant
 2 with key relevant industry standards.” The biometrics industry generally relies on National Institute of
 3 Standards and Technology (NIST) and American National Standards Institute (ANSI) standards. On
 4 information and belief, Atrua’s Wings™ Fingerprint sensor products are not compliant with NIST and
 5 ANSI standards. Thus, Atrua’s claims that its slide or swipe sensors comply with relevant industry
 6 standards are misleading and likely to deceive members of the consuming public and AuthenTec’s
 7 customers or potential customers.

8 34. Atrua’s false and misleading statements also include, but are not limited to, that Atrua
 9 advertises in its “Made-for-Mobile Fingerprint Solutions” materials that its “[p]roven minutia
 10 matching method does not degrade or age like pattern matching.” This false and misleading statement
 11 implies that AuthenTec’s sensors are less reliable. This is false. In the same “Made-for-Mobile
 12 Fingerprint Solutions” materials, Atrua advertises that it is “[t]he leading fingerprint solution for
 13 mobile phones.” This statement is false and misleading. Thus, Atrua’s claims that the matching
 14 method used by its sensors perform better and that it is the industry leader for fingerprint sensors in
 15 mobile phones are false and misleading and likely to deceive members of the consuming public and
 16 AuthenTec’s customers or potential customers.

17 35. Atrua’s false and misleading statements further include, but are not limited to, that
 18 Atrua advertises in its “ATW300 Fingerprint Touch Sensor Family Overview” materials that
 19 “Authentec Requires \$2.56 in Additional BOM Components.” The Bill of Materials identified here for
 20 AuthenTec, however, relate to the personal computer platform rather than the mobile device platform.
 21 Accordingly, this comparison is false and misleading. Thus, Atrua’s claims that its sensors are less
 22 expensive are false and misleading and likely to deceive members of the consuming public and
 23 AuthenTec’s customers or potential customers.

24 36. Atrua’s false and misleading statements about Atrua’s products, AuthenTec, and
 25 AuthenTec’s products, made in the course of commercial advertising or promotion, misrepresents the
 26 nature, characteristics, and qualities of Atrua’s products and AuthenTec’s products.

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37. Atrua makes such false and misleading statements with the specific intent to deceive and mislead customers and potential customers of AuthenTec's products.

38. On information and belief, Atru'a's false and misleading statements have been placed in interstate commerce, have actually deceived customers, create a likelihood that a substantial segment of customers will be deceived, have substantially damaged AuthenTec, and violate 15 U.S.C. § 1125(a).

39. Atrua's acts have substantially damaged AuthenTec's business in an amount to be determined at trial.

40. AuthenTec has been, is now, and will be irreparably injured by Atrua's acts, and unless enjoined by this Court, AuthenTec will suffer further harm to its name, reputation, and goodwill. This harm constitutes an injury for which AuthenTec has no adequate remedy at law.

COUNT 7

(State Unfair Competition – California Business & Professions Code § 17200)

41. Paragraphs 1 through 40 of the Second Amended Complaint set forth above are incorporated herein by reference.

42. Atrua's unlawful, unfair, and/or fraudulent business acts and practices constitute unfair competition in violation of Section 17200 *et seq.* of the California Business & Professions Code.

43. Atrua's statements about Atrua's products, AuthenTec, and AuthenTec's products, made in connection with Atrua's goods or services, falsely and misleadingly describes or represents Atrua's products, AuthenTec, and AuthenTec's products. These statements include, but are not limited to, that Atrua advertises on its website that its Wings™ Fingerprint sensor products are "Compliant with key relevant industry standards." The biometrics industry generally relies on National Institute of Standards and Technology (NIST) and American National Standards Institute (ANSI) standards. On information and belief, Atrua's Wings™ Fingerprint sensor products are not compliant with NIST and ANSI standards. Thus, Atrua's claims that its slide or swipe sensors comply with relevant industry standards are misleading and likely to deceive members of the consuming public and AuthenTec's customers or potential customers.

1 44. Atrua's false and misleading statements also include, but are not limited to, that Atrua
 2 advertises in its "Made-for-Mobile Fingerprint Solutions" materials that its "[p]roven minutia
 3 matching method does not degrade or age like pattern matching." This false and misleading statement
 4 implies that AuthenTec's sensors are less reliable. This is false. In the same "Made-for-Mobile
 5 Fingerprint Solutions" materials, Atrua advertises that it is "[t]he leading fingerprint solution for
 6 mobile phones." This statement is false and misleading. Thus, Atrua's claims that the matching
 7 method used by its sensors perform better and that it is the industry leader for fingerprint sensors in
 8 mobile phones are false and misleading and likely to deceive members of the consuming public and
 9 AuthenTec's customers or potential customers.

10 45. Atrua's false and misleading statements further include, but are not limited to, that
 11 Atrua advertises in its "ATW300 Fingerprint Touch Sensor Family Overview" materials that
 12 "Authentec Requires \$2.56 in Additional BOM Components." The Bill of Materials identified here for
 13 AuthenTec, however, relate to the personal computer platform rather than the mobile device platform.
 14 Accordingly, this comparison is false and misleading. Thus, Atrua's claims that its sensors are less
 15 expensive are false and misleading and likely to deceive members of the consuming public and
 16 AuthenTec's customers or potential customers.

17 46. On information and belief, as a result of Atrua's unlawful, unfair, and/or fraudulent
 18 business acts and practices, AuthenTec has lost money or property and suffered injury in fact.

19 47. AuthenTec is entitled to a judgment enjoining and restraining Atrua from engaging in
 20 further unfair competition and is further entitled to an award of restitution for Atrua's unjust
 21 enrichment.

22 48. Atrua's acts of unfair competition have caused and will continue to cause AuthenTec
 23 irreparable harm. The irreparable harm caused by Atrua to AuthenTec cannot be fully remedied by
 24 restitution alone. Atrua's unlawful, unfair, and/or fraudulent business acts and practices will continue
 25 unless enjoined by the Court.

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COUNT 8**(Common Law Unfair Competition)**

49. Paragraphs 1 through 48 of the Second Amended Complaint set forth above are
incorporated herein by reference.

50. AuthenTec designs, manufactures, and sells fingerprint sensors used in electronic
devices such as personal computers and mobile devices.

51. On information and belief, Atrua also designs and makes fingerprint sensors used in
electronic devices such as mobile telephones.

52. Atrua's acts and practices, including making false statements about Atrua's products,
AuthenTec, and AuthenTec's products, made in connection with Atrua's goods or services, violate the
common law of California.

53. Atrua's statements about Atrua's products, AuthenTec, and AuthenTec's products,
made in connection with Atrua's goods or services, falsely and misleadingly describes or represents
Atrua's products, AuthenTec, and AuthenTec's products. These statements include, but are not limited
to, that Atrua advertises on its website that its Wings™ Fingerprint sensor products are "Compliant
with key relevant industry standards." The biometrics industry generally relies on National Institute of
Standards and Technology (NIST) and American National Standards Institute (ANSI) standards. On
information and belief, Atrua's Wings™ Fingerprint sensor products are not compliant with NIST and
ANSI standards. Thus, Atrua's claims that its slide or swipe sensors comply with relevant industry
standards are misleading and likely to deceive members of the consuming public and AuthenTec's
customers or potential customers.

54. Atrua's false and misleading statements also include, but are not limited to, that Atrua
advertises in its "Made-for-Mobile Fingerprint Solutions" materials that its "[p]roven minutia
matching method does not degrade or age like pattern matching." This false and misleading statement
implies that AuthenTec's sensors are less reliable. This is false. In the same "Made-for-Mobile
Fingerprint Solutions" materials, Atrua advertises that it is "[t]he leading fingerprint solution for
mobile phones." This statement is false and misleading. Thus, Atrua's claims that the matching

method used by its sensors perform better and that it is the industry leader for fingerprint sensors in mobile phones are false and misleading and likely to deceive members of the consuming public and AuthenTec's customers or potential customers.

4 55. Atrua's false and misleading statements further include, but are not limited to, that
5 Atrua advertises in its "ATW300 Fingerprint Touch Sensor Family Overview" materials that
6 "Authentec Requires \$2.56 in Additional BOM Components." The Bill of Materials identified here for
7 AuthenTec, however, relate to the personal computer platform rather than the mobile device platform.
8 Accordingly, this comparison is false and misleading. Thus, Atrua's claims that its sensors are less
9 expensive are false and misleading and likely to deceive members of the consuming public and
10 AuthenTec's customers or potential customers.

56. Atrua's wrongful acts have substantially damaged AuthenTec's business in an amount
to be determined at trial.

13 57. AuthenTec has been, is now, and will be irreparably injured by Atrua's acts, and unless
14 enjoined by this Court, AuthenTec will suffer further harm to its name, reputation, and goodwill. This
15 harm constitutes an injury for which AuthenTec has no adequate remedy at law.

COUNT 9

(Federal False Advertising – Lanham Act § 43(a); 15 U.S.C. § 1125(a))

18 58. Paragraphs 1 through 57 of the Second Amended Complaint set forth above are
19 incorporated herein by reference.

20 59. Atrua's statements about Atrua's products, AuthenTec, and AuthenTec's products,
21 made in connection with Atrua's goods or services, falsely and misleadingly describes or represents
22 Atrua's products, AuthenTec, and AuthenTec's products. These statements include, but are not limited
23 to, that Atrua advertises on its website that its Wings™ Fingerprint sensor products are "Compliant
24 with key relevant industry standards." The biometrics industry generally relies on National Institute of
25 Standards and Technology (NIST) and American National Standards Institute (ANSI) standards. On
26 information and belief, Atrua's Wings™ Fingerprint sensor products are not compliant with NIST and
27 ANSI standards. Thus, Atrua's claims that its slide or swipe sensors comply with relevant industry

1 standards are misleading and likely to deceive members of the consuming public and AuthenTec's
 2 customers or potential customers.

3 60. Atrua's false and misleading statements also include, but are not limited to, that Atrua
 4 advertises in its "Made-for-Mobile Fingerprint Solutions" materials that its "[p]roven minutia
 5 matching method does not degrade or age like pattern matching." This false and misleading statement
 6 implies that AuthenTec's sensors are less reliable. This is false. In the same "Made-for-Mobile
 7 Fingerprint Solutions" materials, Atrua advertises that it is "[t]he leading fingerprint solution for
 8 mobile phones." This statement is false and misleading. Thus, Atrua's claims that the matching
 9 method used by its sensors perform better and that it is the industry leader for fingerprint sensors in
 10 mobile phones are false and misleading and likely to deceive members of the consuming public and
 11 AuthenTec's customers or potential customers.

12 61. Atrua's false and misleading statements further include, but are not limited to, that
 13 Atrua advertises in its "ATW300 Fingerprint Touch Sensor Family Overview" materials that
 14 "Authentec Requires \$2.56 in Additional BOM Components." The Bill of Materials identified here for
 15 AuthenTec, however, relate to the personal computer platform rather than the mobile device platform.
 16 Accordingly, this comparison is false and misleading. Thus, Atrua's claims that its sensors are less
 17 expensive are false and misleading and likely to deceive members of the consuming public and
 18 AuthenTec's customers or potential customers.

19 62. Atrua's false and misleading statements about Atrua's products, AuthenTec, and
 20 AuthenTec's products, made in the course of commercial advertising or promotion, misrepresents the
 21 nature, characteristics, and qualities of Atrua's products and AuthenTec's products.

22 63. Atrua makes such false and misleading statements with the specific intent to deceive
 23 and mislead customers and potential customers of AuthenTec's products.

24 64. On information and belief, Atrua's false and misleading statements have been placed in
 25 interstate commerce, have actually deceived customers, create a likelihood that a substantial segment
 26 of customers will be deceived, have substantially damaged AuthenTec, and violate 15 U.S.C. §
 27 1125(a).

28

65. Atrua's acts have substantially damaged AuthenTec's business in an amount to be determined at trial.

66. AuthenTec has been, is now, and will be irreparably injured by Atrua's acts, and unless enjoined by this Court, AuthenTec will suffer further harm to its name, reputation, and goodwill. This harm constitutes an injury for which AuthenTec has no adequate remedy at law.

COUNT 10

(State False Advertising – California Business & Professions Code § 17500)

67. Paragraphs 1 through 66 of the Complaint set forth above are incorporated herein by reference.

68. Atrua purposefully and intentionally made or disseminated or caused to be made or disseminated to the public unfair, deceptive, untrue, and/or misleading statements and/or advertising about Atrua's products, AuthenTec, and AuthenTec's products in violation of Section 17500 *et seq.* of the California Business & Professions code.

69. Atrua's statements about Atrua's products, AuthenTec, and AuthenTec's products, made in connection with Atrua's goods or services, falsely and misleadingly describes or represents Atrua's products, AuthenTec, and AuthenTec's products. These statements include, but are not limited to, that Atrua advertises on its website that its Wings™ Fingerprint sensor products are "Compliant with key relevant industry standards." The biometrics industry generally relies on National Institute of Standards and Technology (NIST) and American National Standards Institute (ANSI) standards. On information and belief, Atrua's Wings™ Fingerprint sensor products are not compliant with NIST and ANSI standards. Thus, Atrua's claims that its slide or swipe sensors comply with relevant industry standards are misleading and likely to deceive members of the consuming public and AuthenTec's customers or potential customers.

70. Atrua's false and misleading statements also include, but are not limited to, that Atrua advertises in its "Made-for-Mobile Fingerprint Solutions" materials that its "[p]roven minutia matching method does not degrade or age like pattern matching." This false and misleading statement implies that AuthenTec's sensors are less reliable. This is false. In the same "Made-for-Mobile

1 Fingerprint Solutions” materials, Atrua advertises that it is “[t]he leading fingerprint solution for
2 mobile phones.” This statement is false and misleading. Thus, Atrua’s claims that the matching
3 method used by its sensors perform better and that it is the industry leader for fingerprint sensors in
4 mobile phones are false and misleading and likely to deceive members of the consuming public and
5 AuthenTec’s customers or potential customers.

6 71. Atrua's false and misleading statements further include, but are not limited to, that
7 Atrua advertises in its "ATW300 Fingerprint Touch Sensor Family Overview" materials that
8 "Authentec Requires \$2.56 in Additional BOM Components." The Bill of Materials identified here for
9 AuthenTec, however, relate to the personal computer platform rather than the mobile device platform.
10 Accordingly, this comparison is false and misleading. Thus, Atrua's claims that its sensors are less
11 expensive are false and misleading and likely to deceive members of the consuming public and
12 AuthenTec's customers or potential customers.

13 72. In making and disseminating the statements and/or advertisements, Atrua knew or
14 should have known that the statements and/or advertisements were untrue or misleading and were in
15 violation of California Business & Professions code § 17500 *et seq.*

16 73. On information and belief, Atrua's acts have substantially damaged AuthenTec's
17 business, substantially damaged consumers' interests, and unjustly enriched Atrua, and will continue to
18 do so unless enjoined by the Court.

19 74. Atrua's acts have caused and will continue to cause AuthenTec irreparable harm.
20 AuthenTec has no adequate remedy at law for Atrua's wrongful conduct.

21 75. AuthenTec is entitled to a judgment enjoining and restraining Atrua from engaging in
22 further wrongful conduct and is further entitled to an award of restitution for Atrua's unjust
23 enrichment.

COUNT 11

(Intentional Interference with Prospective Economic Advantage)

26 76. Paragraphs 1 through 75 of the Second Amended Complaint set forth above are
27 incorporated herein by reference.

1 77. AuthenTec had economic relationships with potential customers that contained the
 2 probability of future economic benefit or advantage to AuthenTec.

3 78. Atrua knew of the existence of these relationships.

4 79. Atrua made and/or disseminated wrongful, unfair, unlawful, and fraudulent statements
 5 about Atrua's products, AuthenTec, and AuthenTec's products, designed to interfere with or disrupt
 6 these relationships.

7 80. Atrua intended to interfere with and disrupt these relationships through its wrongful,
 8 unfair, unlawful, and fraudulent statements, or had knowledge that its interference or disruption was
 9 certain or substantially certain to occur as a result of its actions.

10 81. On information and belief, Atrua's actions interfered with or disrupted AuthenTec's
 11 prospective customer relationships and other prospective economic advantages.

12 82. Atrua's statements about Atrua's products, AuthenTec, and AuthenTec's products,
 13 made in connection with Atrua's goods or services, falsely and misleadingly describes or represents
 14 Atrua's products, AuthenTec, and AuthenTec's products. These statements include, but are not limited
 15 to, that Atrua advertises on its website that its Wings™ Fingerprint sensor products are "Compliant
 16 with key relevant industry standards." The biometrics industry generally relies on National Institute of
 17 Standards and Technology (NIST) and American National Standards Institute (ANSI) standards. On
 18 information and belief, Atrua's Wings™ Fingerprint sensor products are not compliant with NIST and
 19 ANSI standards. Thus, Atrua's claims that its slide or swipe sensors comply with relevant industry
 20 standards are misleading and likely to deceive members of the consuming public and AuthenTec's
 21 customers or potential customers.

22 83. Atrua's false and misleading statements also include, but are not limited to, that Atrua
 23 advertises in its "Made-for-Mobile Fingerprint Solutions" materials that its "[p]roven minutia
 24 matching method does not degrade or age like pattern matching." This false and misleading statement
 25 implies that AuthenTec's sensors are less reliable. This is false. In the same "Made-for-Mobile
 26 Fingerprint Solutions" materials, Atrua advertises that it is "[t]he leading fingerprint solution for
 27 mobile phones." This statement is false and misleading. Thus, Atrua's claims that the matching

1 method used by its sensors perform better and that it is the industry leader for fingerprint sensors in
 2 mobile phones are false and misleading and likely to deceive members of the consuming public and
 3 AuthenTec's customers or potential customers.

4 84. Atrua's false and misleading statements further include, but are not limited to, that
 5 Atrua advertises in its "ATW300 Fingerprint Touch Sensor Family Overview" materials that
 6 "Authentec Requires \$2.56 in Additional BOM Components." The Bill of Materials identified here for
 7 AuthenTec, however, relate to the personal computer platform rather than the mobile device platform.
 8 Accordingly, this comparison is false and misleading. Thus, Atrua's claims that its sensors are less
 9 expensive are false and misleading and likely to deceive members of the consuming public and
 10 AuthenTec's customers or potential customers.

11 85. Atrua's wrongful actions, designed to interfere with or disrupt AuthenTec's economic
 12 relationships, have substantially damaged AuthenTec's business in an amount to be determined at trial.

13 86. Atrua's interference was and is oppressive, fraudulent, and malicious, and was and is
 14 intended to obtain an unfair and improper competitive advantage, warranting an award of punitive
 15 damages to AuthenTec.

COUNT 12

(Trade Libel and Defamation)

18 87. Paragraphs 1 through 86 of the Second Amended Complaint set forth above are
 19 incorporated herein by reference.

20 88. AuthenTec designs, manufactures, and sells fingerprint sensors used in electronic
 21 devices such as personal computers and mobile devices.

22 89. On information and belief, Atrua also designs and makes fingerprint sensors used in
 23 electronic devices such as mobile telephones.

24 90. Atrua published, made, and/or disseminated wrongful, unfair, unlawful, and fraudulent
 25 statements about Atrua's products, AuthenTec, and AuthenTec's products to AuthenTec's customers,
 26 potential customers, and/or potential business partners. Atrua's statements disparaged and
 27 misrepresented the quality and characteristics of AuthenTec's products.

28

1 91. Atrua's statements about Atrua's products, AuthenTec, and AuthenTec's products were
 2 false. Atrua intentionally made such statements with the knowledge that they were false or with
 3 reckless disregard for their truth or falsity.

4 92. On information and belief, Atrua's actions interfered with or disrupted AuthenTec's
 5 relationships with customers, potential customers, and/or potential business partners.

6 93. Atrua's false and misleading statements include, but are not limited to, that Atrua
 7 advertises in its "Made-for-Mobile Fingerprint Solutions" materials that its "[p]roven minutia
 8 matching method does not degrade or age like pattern matching." This false and misleading statement
 9 implies that AuthenTec's sensors are less reliable. This is false. In the same "Made-for-Mobile
 10 Fingerprint Solutions" materials, Atrua advertises that it is "[t]he leading fingerprint solution for
 11 mobile phones." This statement is false and misleading. Thus, Atrua's claims that the matching
 12 method used by its sensors perform better and that it is the industry leader for fingerprint sensors in
 13 mobile phones are false and misleading and likely to deceive members of the consuming public and
 14 AuthenTec's customers or potential customers.

15 94. Atrua's false and misleading statements further include, but are not limited to, that
 16 Atrua advertises in its "ATW300 Fingerprint Touch Sensor Family Overview" materials that
 17 "Authentec Requires \$2.56 in Additional BOM Components." The Bill of Materials identified here for
 18 AuthenTec, however, relate to the personal computer platform rather than the mobile device platform.
 19 Accordingly, this comparison is false and misleading. Thus, Atrua's claims that its sensors are less
 20 expensive are false and misleading and likely to deceive members of the consuming public and
 21 AuthenTec's customers or potential customers.

22 95. Atrua's wrongful actions, designed to interfere with or disrupt AuthenTec's business
 23 relationships, have substantially damaged AuthenTec's business in an amount to be determined at trial.

24 96. Atrua's interference was and is oppressive, fraudulent, and malicious, and was and is
 25 intended to obtain an unfair and improper competitive advantage, warranting an award of punitive
 26 damages to AuthenTec.

27

28

COUNT 13**(Declaration of Non-Infringement of U.S. Patent No. 7,197,168)**

97. Paragraphs 1 through 96 of the Second Amended Complaint set forth above are incorporated herein by reference.

98. Based upon Atrua's filing of its counterclaims and AuthenTec's affirmative defenses, an actual controversy has arisen and now exists between the parties as to whether any of AuthenTec's products infringe any valid and enforceable claim of U.S. Patent No. 7,197,168 ("the '168 patent").

99. AuthenTec's products do not infringe and have never infringed any valid and enforceable claim of the '168 patent, either literally or under the doctrine of equivalents, nor is AuthenTec actively inducing or contributing to the infringement of the '168 patent. Therefore, AuthenTec is not liable for any damage purportedly arising from Atrua's accusation of infringement.

100. AuthenTec desires and requests judicial determination and declaration of the respective rights and duties of the parties based on the disputes recited above. Such a determination and resulting declaration are necessary and appropriate at this time so that the parties may ascertain their respective rights and duties regarding the noninfringement of the '168 patent.

101. Under the Federal Declaratory Judgment Act, 28 U.S.C. § 2201 *et seq.*, AuthenTec accordingly requests a declaration from the Court that AuthenTec does not infringe any claim of the '168 patent in any way.

COUNT 14**(Declaration of Invalidity of the '168 patent)**

102. Paragraphs 1 through 101 of the Second Amended Complaint set forth above are incorporated herein by reference.

103. The '168 patent, and each claim thereof, is invalid for failure to comply with the conditions and requirements of patentability set forth in Title 35 of the United States Code, particularly 35 U.S.C. § 101, *et seq.*

104. The '168 patent, and each claim thereof, is invalid for failure to comply with the provisions of 35 U.S.C. § 102.

105. The '168 patent, and each claim thereof, is invalid for failure to comply with the provisions of 35 U.S.C. § 103.

106. The '168 patent, and each claim thereof, is invalid for failure to comply with the provisions of 35 U.S.C. § 112.

107. AuthenTec desires and requests judicial determination and declaration of the respective rights and duties of the parties based on the disputes recited above. Such a determination and resulting declaration are necessary and appropriate at this time so that the parties may ascertain their respective rights and duties regarding the invalidity of the '168 patent.

108. Under the Federal Declaratory Judgment Act, 28 U.S.C. § 2201 *et seq.*, AuthenTec accordingly requests a declaration from the Court that the '168 patent is invalid and unenforceable.

PRAAYER FOR RELIEF

WHEREFORE, AuthenTec respectfully requests that this Court enter judgment against Atrua as follows:

a) For judgment that Atrua has infringed and continues to infringe the ‘248 Patent, the ‘439 Patent, ‘526 Patent, the ‘679 Patent, and the ‘804 Patent;

b) For preliminary and permanent injunctions under 35 U.S.C. § 283 against Atrua and its directors, officers, employees, agents, servants, subsidiaries, parents, successors, assigns, attorneys, and all persons acting in concert, on behalf of, in joint venture with, or in partnership with Atrua from further infringing acts;

c) For damages to be paid by Atrua adequate to compensate AuthenTec for Atrua's infringement, including interests, costs, and disbursements as the Court may deem appropriate under 35 U.S.C. § 284;

d) For judgment finding that Atrua's infringement was willful and deliberate, entitling AuthenTec to increased damages under 35 U.S.C. § 284;

- e) For judgment finding this to be an exceptional case, and awarding AuthenTec attorneys' fees and costs under 35 U.S.C. § 285;

1 f) For judgment requiring that Atrua and its officers, agents, servants, employees, owners,
2 and representatives, and all other persons, firms, or corporations in active concert or participation with
3 it, be enjoined and restrained from making false, misleading, unlawful, unfair, and fraudulent
4 statements about Atrua's products, AuthenTec, and AuthenTec's products to AuthenTec's customers,
5 potential customers, and/or potential business partners;

6 g) For judgment requiring that Atrua and its officers, agents, servants, employees, owners,
7 and representatives, and all other persons, firms, or corporations in active concert or participation with
8 it, be enjoined and restrained from further acts of unfair competition, false advertising, trade libel, and
9 interference with prospective economic advantage;

10 h) For judgment declaring that AuthenTec does not infringe any valid and enforceable
11 claim of the '168 patent in any way;

i) For judgment declaring that each claim of the '168 patent is invalid;

13 j) For judgment that Atrua is not entitled to any injunctive relief;

14 k) For damages to be paid by Atrua adequate to compensate AuthenTec for Atrua's unfair
15 competition, trade libel, interference with prospective economic advantage, and Lanham Act
16 violations;

17 l) For restitution and recovery of Atrua's unjust enrichment;

18 m) For prejudgment interest;

19 n) For exemplary damages as appropriate and permitted by law;

20 o) For reasonable attorneys' fees and costs as appropriate and permitted by law; and

21 p) For such other and further relief at law and in equity as the Court may deem just and
22 proper.

23 || Dated: July 30, 2008

Respectfully submitted,

HOWREY LLP

By: /s/ Denise M. De Mory
Denise M. De Mory
Attorneys for Plaintiff
AuthenTec, Inc.

DEMAND FOR JURY TRIAL

AuthenTec hereby demands a trial by jury on all issues set forth in its Complaint for Patent Infringement, Unfair Competition, False Advertising, Interference with Prospective Economic Advantage, and Trade Libel pursuant to Fed. R. Civ. P. 38 and Civ. L.R. 3-6.

Dated: July 30, 2008

Respectfully submitted,

HOWREY LLP

By: /s/ Denise M. De Mory

Denise M. De Mory

Attorneys for Plaintiff

EXHIBIT A



US005862248A

United States Patent [19]

Salatino et al.

[11] Patent Number: **5,862,248**
 [45] Date of Patent: **Jan. 19, 1999**

[54] **INTEGRATED CIRCUIT DEVICE HAVING AN OPENING EXPOSING THE INTEGRATED CIRCUIT DIE AND RELATED METHODS**

[75] Inventors: **Matthew M. Salatino**, Satellite Beach; **S. James Studebaker**, Palm Bay; **Nicolaas W. VanVonno**, Melbourne, all of Fla.

[73] Assignee: **Harris Corporation**, Palm Bay, Fla.

[21] Appl. No.: **671,430**

[22] Filed: **Jun. 27, 1996**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 592,472, Jan. 26, 1996.

[51] Int. Cl.⁶ **G06K 9/28**

[52] U.S. Cl. **382/124; 382/312; 438/127**

[58] Field of Search 382/116, 124, 382/125, 126, 127, 312, 313, 314, 315; 356/71; 438/15, 51, 55, 64, 60, 112, 116, 119, 124, 126, 127; 324/348, 457; 340/825.34; 361/181; 264/272.17; 364/468.28; 427/96; 399/3; 348/272, 294, 311, 306

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Primary Examiner—Leo H. Boudreau

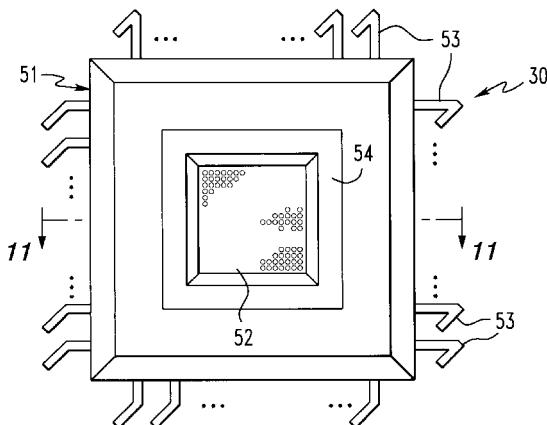
Assistant Examiner—Brian P. Werner

Attorney, Agent, or Firm—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

[57]

ABSTRACT

An integrated circuit device, such as a fingerprint sensing device, includes an integrated circuit die, a body of encapsulating material surrounding the integrated circuit die and having an opening therein exposing a portion of the integrated circuit die, and an electrically conductive member or frame being mounted to the body of encapsulating material adjacent the opening therein. The electrically conductive member may preferably be positioned so as to define at least a portion of a frame for the opening in the body of encapsulating material. The electrically conductive member may be adhesively secured to the integrated circuit die. Accordingly, the adhesive and electrically conductive member may serve as a seal to the interface between the body of encapsulating material and the die. The electrically conductive member may define a frame that surrounds a body of removable material during an intermediate stage in manufacturing. More particularly, the body of removable material and its frame may be positioned on the integrated circuit die while plastic is injection molded to encapsulate the assembly.

39 Claims, 6 Drawing Sheets

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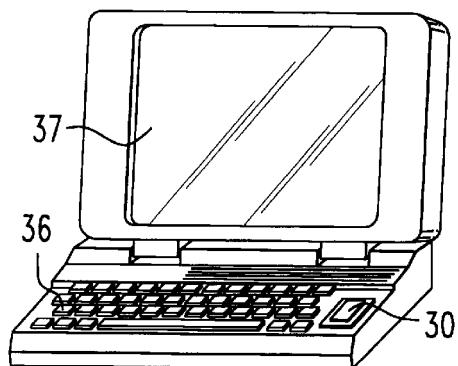
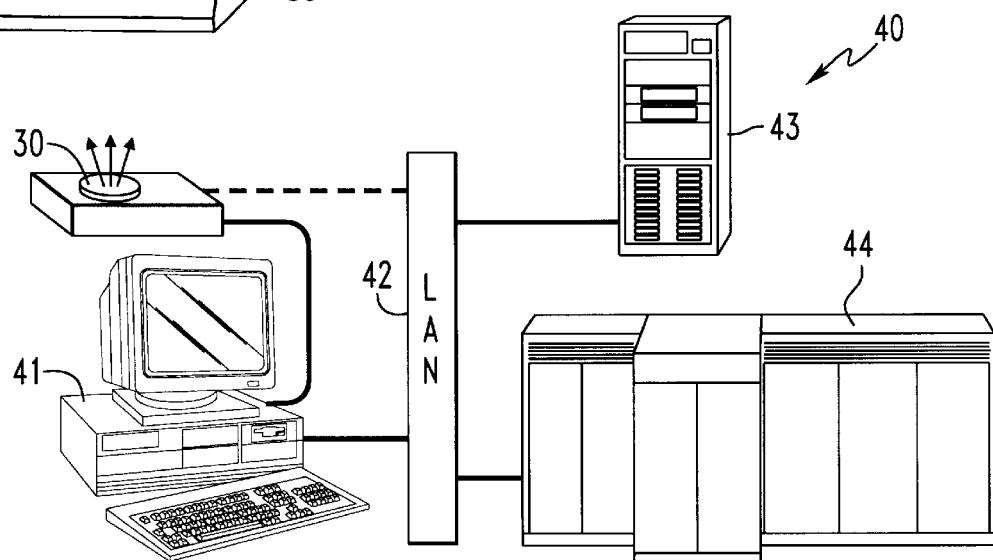
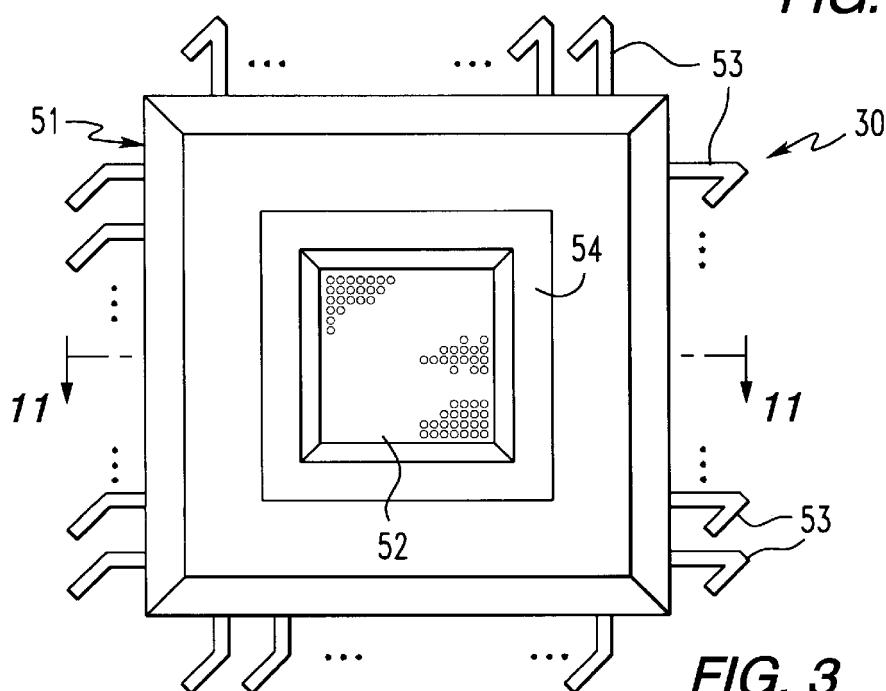
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5,862,248**FIG. 1****FIG. 2****FIG. 3**

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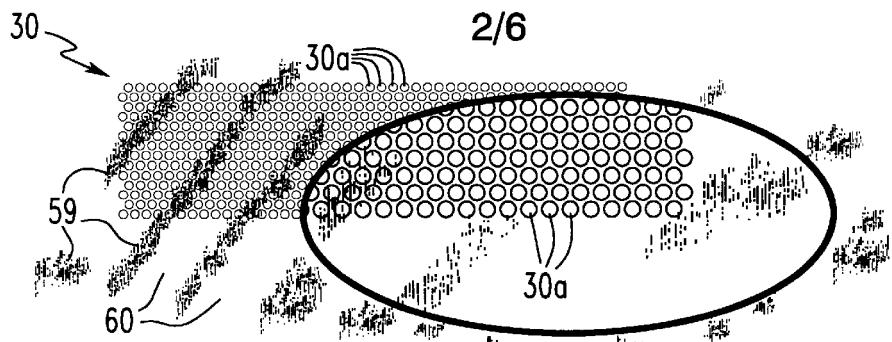


FIG. 4

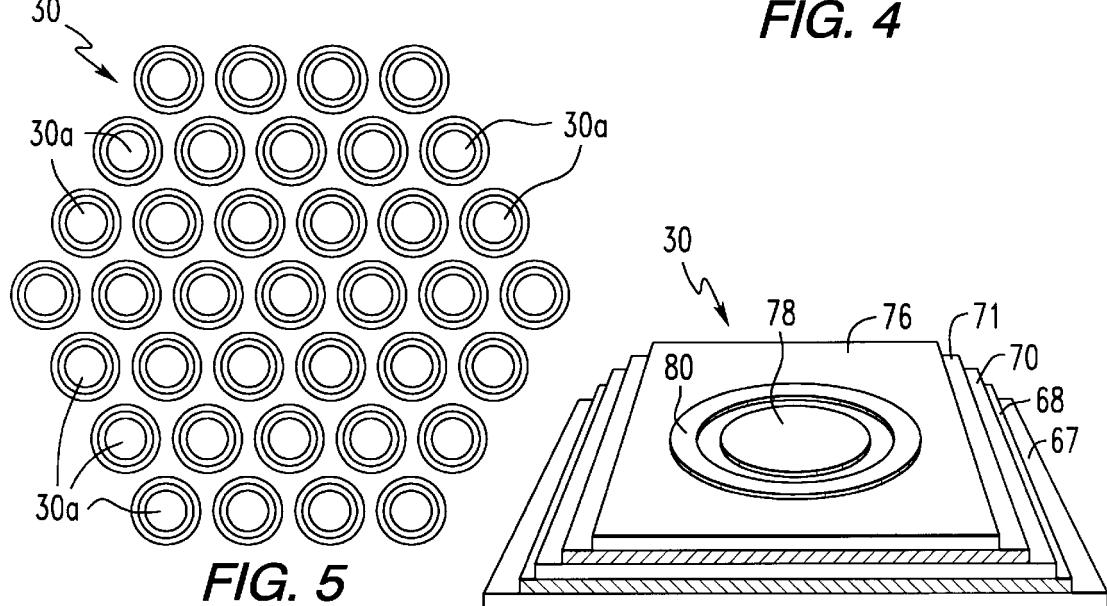


FIG. 5

FIG. 6

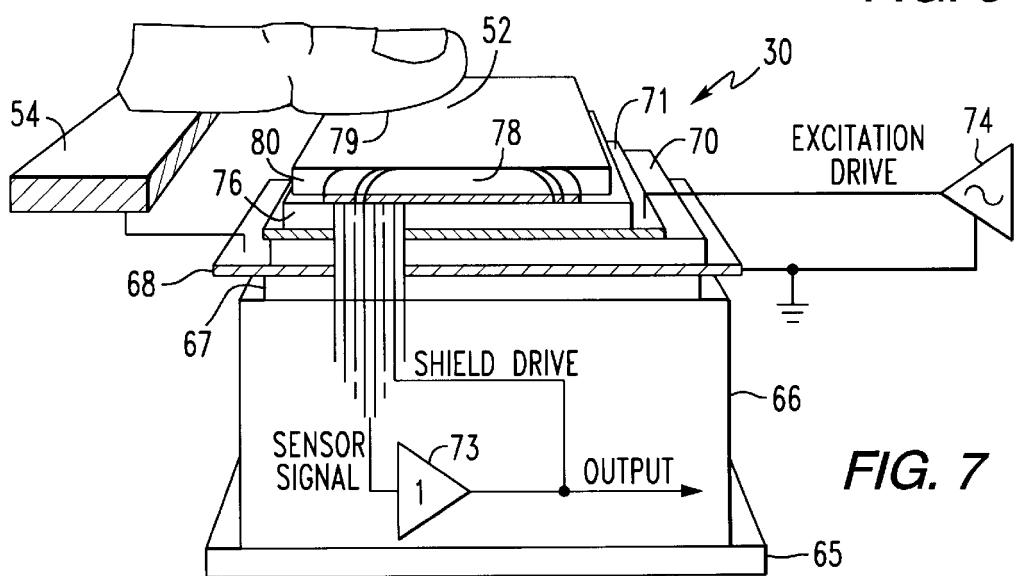


FIG. 7

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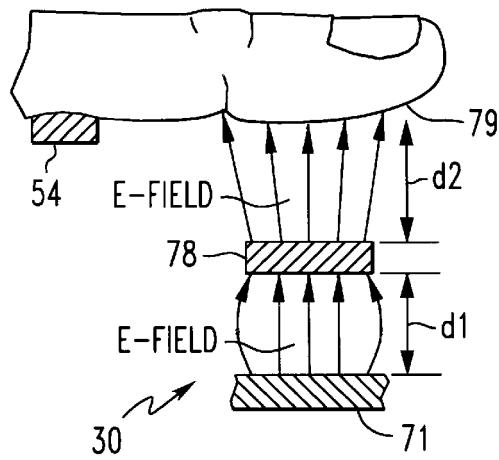


FIG. 8

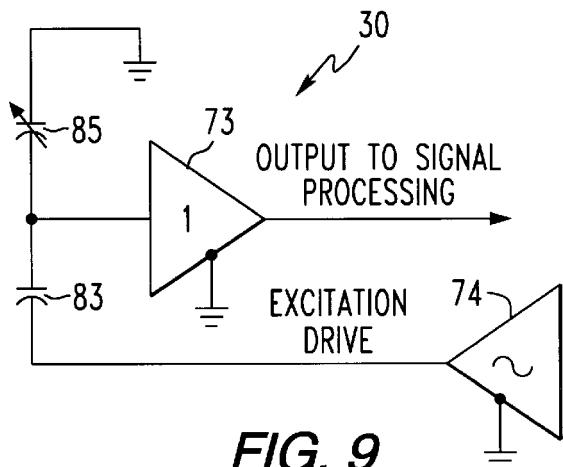


FIG. 9

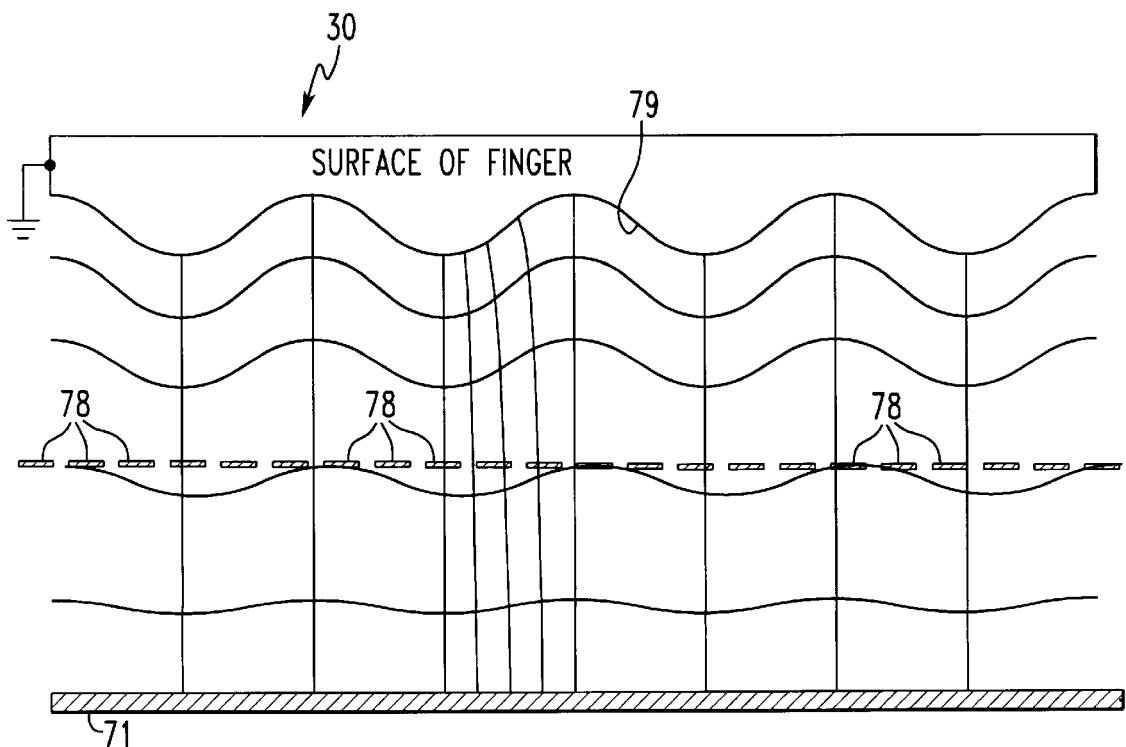


FIG. 10

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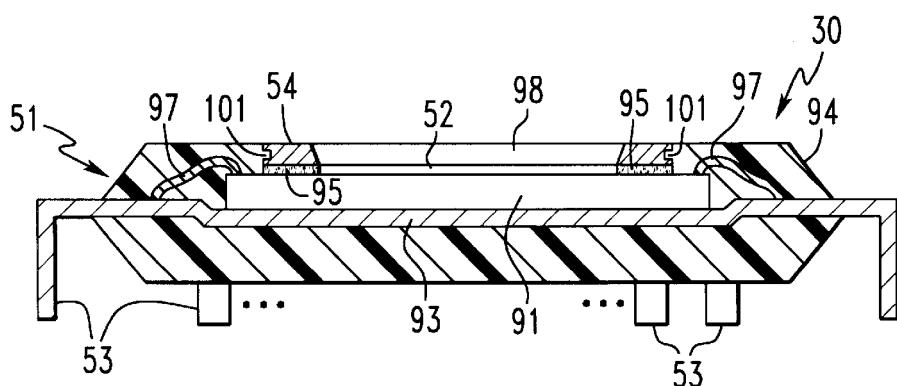


FIG. 11

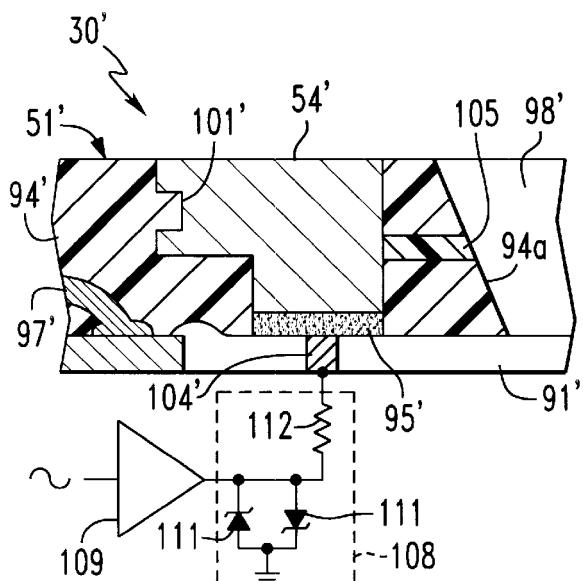


FIG. 12

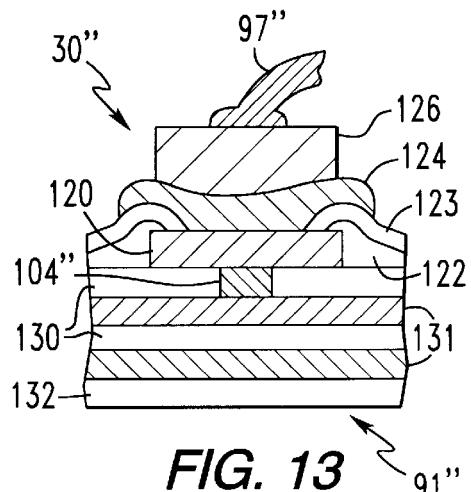


FIG. 13

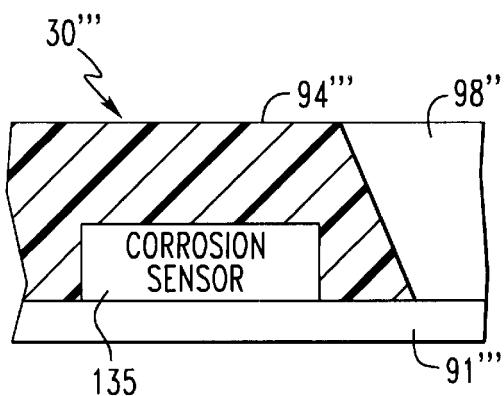


FIG. 14

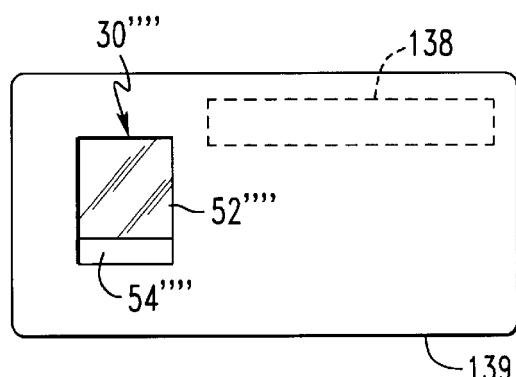


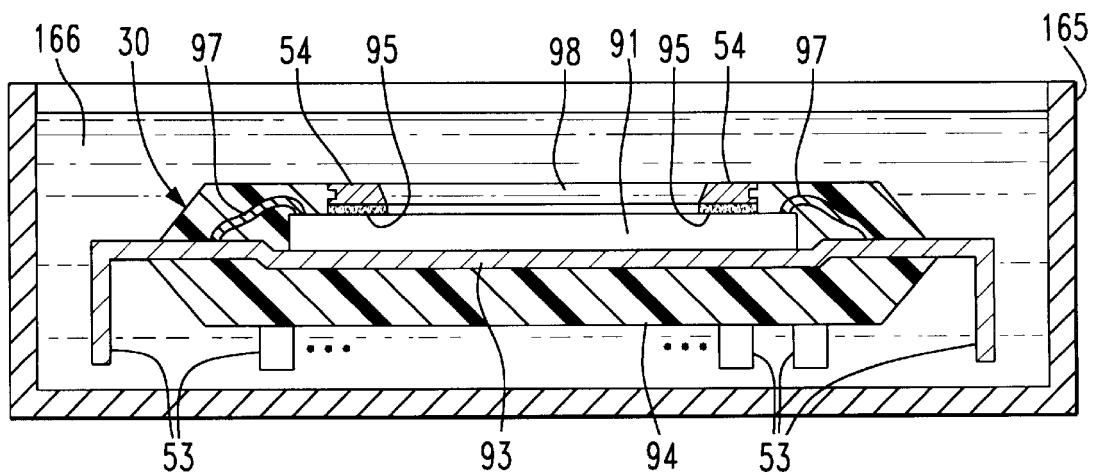
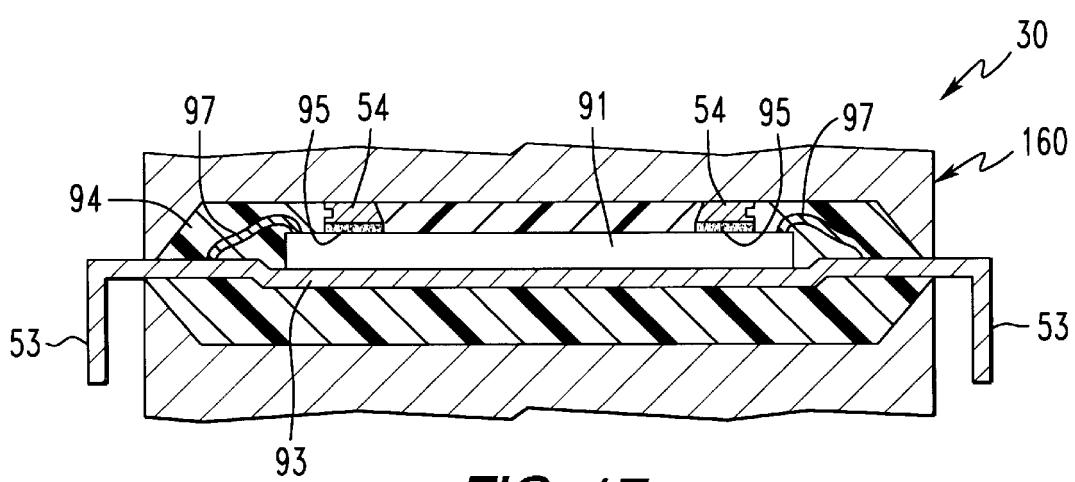
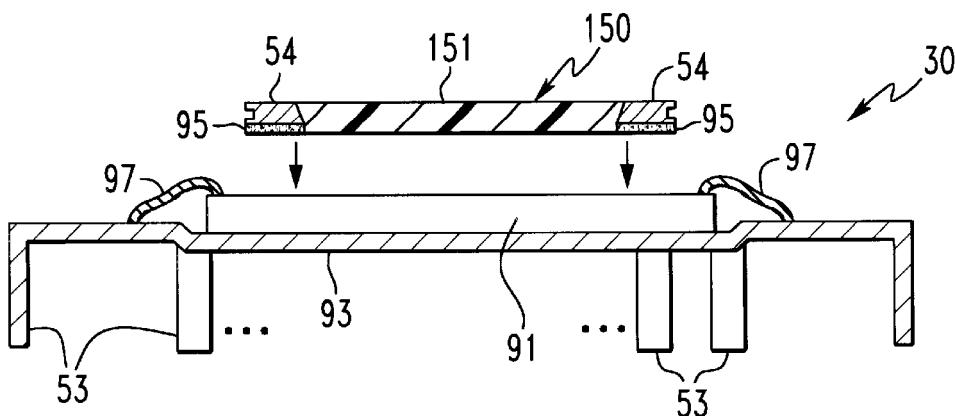
FIG. 15

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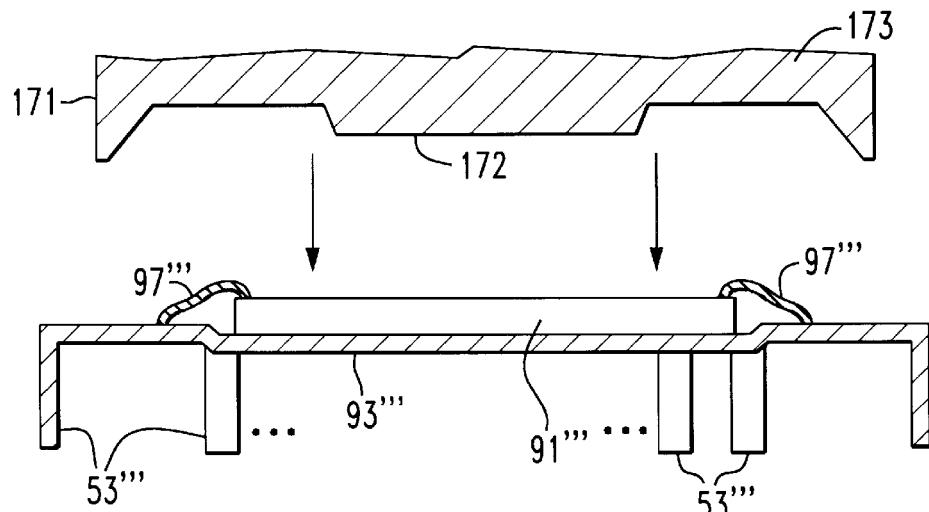


FIG. 19

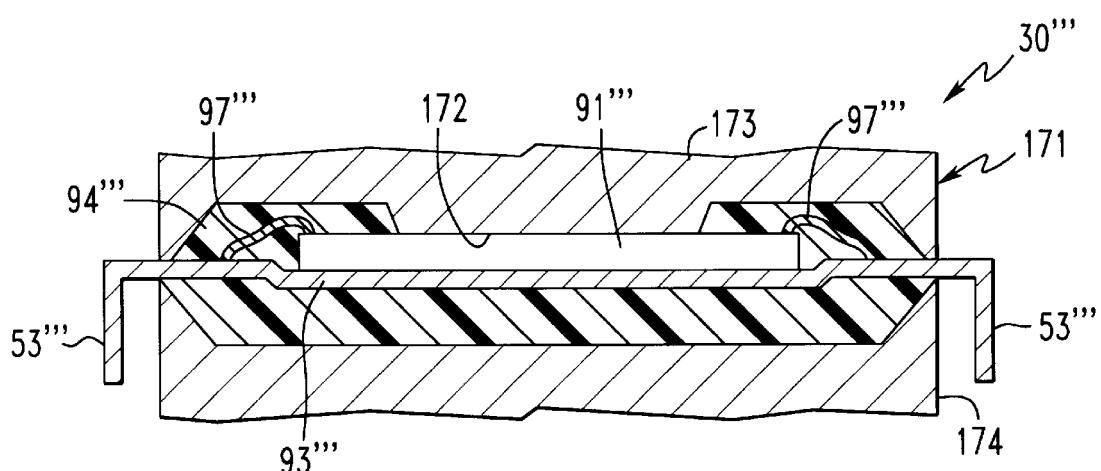


FIG. 20

**INTEGRATED CIRCUIT DEVICE HAVING
AN OPENING EXPOSING THE
INTEGRATED CIRCUIT DIE AND RELATED
METHODS**

RELATED APPLICATION

This application is a continuation-in-part application of U.S. patent application Ser. No. 08/592,472 filed Jan. 26, 1996.

FIELD OF THE INVENTION

The present invention relates to the field of semiconductors, and, more particularly, to an integrated circuit device and package therefor.

BACKGROUND OF THE INVENTION

Several applications may require that the outermost surface of an integrated circuit die be exposed to the environment, such as to be accessible for direct contact with a person or part of a person. For example, certain medical applications position a bare integrated circuit into the blood stream, such as to measure blood chemistry. Fortunately, in such an application the circuit's operational life is limited, and the circuit is used only once before being discarded. Accordingly, long term reliability is not typically a significant issue.

In contrast, a fingerprint sensor based upon an integrated circuit array of sensing elements may require direct contact by the finger with the integrated circuit die. Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. One common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in storage to determine proper identification of a person, such as for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. For example, U.S. Pat. No. 4,210,899 to Swonger et al. discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. U.S. Pat. No. 4,525,859 to Bowles similarly discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. In addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams. Accordingly, optical sensors may thus be bulky and be susceptible to shock, vibration and surface contamination. Accordingly, an optical fingerprint sensor may be unreliable in service in addition to being bulky and relatively expensive due to optics and moving parts.

U.S. Pat. No. 4,353,056 to Tsikos discloses another approach to sensing a live fingerprint. In particular, the patent discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques. Unfortunately, the resilient materials required for the sensor may suffer from long term reliability problems. In addition, multiplexing techniques for driving and scanning each of the individual capacitors may be relatively slow and cumbersome. Moreover, noise and stray capacitances may adversely affect the plurality of relatively small and closely spaced capacitors.

U.S. Pat. No. 5,325,442 to Knapp discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying portion of the finger surface which, in turn, is at ground potential. The sensor may be fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes. Further conductors may be provided on the surface of the dielectric material remote from the sensing electrodes and extending over regions between the sensing electrodes, for example, as lines or in grid form, which conductors are grounded in order to improve the electrical contact to the finger surface.

Unfortunately, driving the array of closely spaced sensing electrodes as disclosed in the Knapp et al. patent may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. Yet another difficulty with such a sensor, as with many optical sensors, is that different portions of the fingerprint may require relatively complicated post image collection processing to provide for usable signal levels and contrast to thereby permit accurate determination of the ridges and valleys of the fingerprint.

Greater advances in fingerprint sensing and matching for identification and verification are desirable and may prevent unauthorized use of computer workstations, appliances, vehicles, and confidential data. Inexpensive and effective fingerprint identification may also be used at point-of-sale terminals, and ensure further security of credit and debit cards, firearms, and provide a personal electronic signature. Unfortunately, current sensors and their associated circuitry may be too bulky, expensive and unreliable for a great many applications which would otherwise benefit from fingerprint identification and verification technology.

Even though several integrated circuit approaches to fingerprint sensing have been described, there are significant difficulties in packaging such a sensor. As mentioned above, direct physical contact with an integrated circuit die is counter to conventional integrated circuit manufacturing and packaging concepts. Water vapor and other contaminants may enter any interface between the integrated circuit die and the surrounding package thereby potentially significantly reducing reliability. Moreover, even if a reliable package were to be designed, low cost mass production techniques would still be desirable for implementing the

packaging design. Other sensors and integrated circuit devices may also desirably benefit from packaging advances which provide an integrated circuit device including a package which exposes the integrated circuit die, yet which provides environmental protection for other portions of the die, such as the bond pads and bond wires.

SUMMARY OF THE INVENTION

In view of the foregoing background, it is therefore an object of the present invention to provide an integrated circuit device and related methods permitting direct contact of the integrated circuit die by the sensed medium, such as the finger of a user, for example, and while providing a reliable environmental seal for the die.

It is another object of the present invention to provide such an integrated circuit device and related methods which facilitate large scale and relatively low cost manufacturing.

These and other objects, advantages and features of the present invention are provided in one embodiment by a fingerprint sensing device comprising an integrated circuit die, a body of encapsulating material surrounding the integrated circuit die and having an opening therein exposing a fingerprint sensing portion of the die, and an electrically conductive member or frame being mounted to the body of encapsulating material adjacent the opening therein. The electrically conductive member may preferably be positioned so as to define at least a portion of a frame for the opening in the body of encapsulating material. In one embodiment, the electrically conductive member may have a closed geometric shape and define a complete frame for the opening.

The electrically conductive member may be adhesively secured to the integrated circuit die. Accordingly, the electrically conductive member, and adhesive may serve to seal the interface between the body of encapsulating material and the die. The electrically conductive member may define a frame that surrounds a body of removable material during an intermediate stage in manufacturing. More particularly, the body of removable material and its frame may be positioned on the integrated circuit die while plastic is injection molded to encapsulate the assembly. The body of removable material may then be removed thereby forming the opening in the body of encapsulating material and leaving the electrically conductive frame secured to the surrounding body of encapsulating material. In this embodiment, the electrically conductive member defines a frame during manufacturing and facilitates formation of the opening to expose the adjacent portion of the integrated circuit die. The electrically conductive member may also be part of the circuitry of the integrated circuit device.

The integrated circuit device may preferably include interconnection means for electrically connecting the electrically conductive member to the integrated circuit die. For example, the interconnection means may include an electrically conductive adhesive between the electrically conductive member and the integrated circuit die, and at least one conductor filled via in the integrated circuit die.

For a fingerprint sensing embodiment of the invention, the integrated circuit die may comprise an electric field fingerprint sensor. More particularly, the electric field fingerprint sensor may preferably comprise an array of electric field sensing electrodes, a dielectric layer adjacent the electric field sensing electrodes, and drive means for applying an electric field drive signal to the electric field sensing electrodes and adjacent portions of the finger so that the electric field sensing electrodes produce a fingerprint image signal.

Accordingly, the electrically conductive member may serve as an electrode for the fingerprint sensing portion.

Another aspect of the present invention is based upon the user contacting the integrated circuit device, such as to sense a fingerprint. Since the electrically conductive member is contacted by the finger of the user, voltage clamping means is preferably operatively connected to the electrically conductive member for clamping a voltage thereof to remove electrostatic buildup to thereby protect the integrated circuit device from electrostatic discharge damage and/or to protect the user from electrical shock when contacting the integrated circuit device.

The integrated circuit die preferably further comprises a plurality of bond pads. Accordingly, the body of encapsulating material preferably covers the plurality of bond pads. In addition, bond pad sealing means may be provided for protecting the plurality of bond pads from corrosion. Each of the bond pads may comprise a first metal layer, such as comprising aluminum. Accordingly, the bond pad sealing means may comprise a barrier metal layer on the first metal layer. The bond pad sealing means may further comprise a layer of gold on the barrier metal layer. The bond pad sealing means may be used with the electrically conductive member providing a frame and sealing the interface with the die. Alternatively, in some embodiments the bond pad sealing means may be used without the electrically conductive member or frame member.

The body of encapsulating material preferably comprises injection molded plastic. Locking means is preferably defined at an interface between the electrically conductive member or frame member and the body of encapsulating material for forming a mechanical lock therebetween. Corrosion sensing means may be associated with the integrated circuit die to provide a further backup to ensure reliability such as by indicating the integrated circuit's feasible end of life. The integrated circuit device may also comprise a lead frame connected to the integrated circuit die. In addition, the electrically conductive member may comprise a metal, such as gold, for example. The integrated circuit die preferably comprises a robust outermost passivating layer of at least one of a nitride, carbide, or diamond, for example.

Another aspect of the invention is that the integrated circuit die may comprise a relatively rigid substrate, such as a silicon substrate, and a plurality of metal layers on the substrate. The metal layers are preferably relatively thin and relatively rigid to provide additional strength to the integrated circuit die, since the die is typically touched by the user. Preferably each of the plurality of metal layers comprises a refractory metal, such as tungsten, molybdenum, or titanium. Considered another way, according to this aspect of the invention each of the plurality of metal layers is preferably devoid of relatively soft aluminum.

A method aspect according to the present invention is for making an integrated circuit device. The method preferably comprises the steps of: providing an integrated circuit die; positioning a body of removable material on the integrated circuit die; forming a body of encapsulating material around the integrated circuit die and the body of removable material; and removing the body of removable material to define an opening through the body of encapsulating material to expose a portion of the integrated circuit die. The integrated circuit die may be a sensor, such as a fingerprint sensor, or other integrated circuit device.

The method may further comprise the step of securing a frame member to the body of removable material. The frame member may comprise an electrically conductive material.

In addition, the step of removing the body of removable material preferably includes removing same while the frame member remains in place with the body of encapsulating material. The step of positioning the body of removable material preferably includes the step of adhesively securing the frame member to the integrated circuit die. The step of forming the body of encapsulating material may include injection molding plastic around the body of removable material and the integrated circuit die. In addition, the body of removable material may preferably be a body of material soluble in liquid, and wherein the step of removing preferably includes exposing the body of material to the liquid solvent.

Another method aspect of the invention is for making an integrated circuit device comprising the steps of: providing an integrated circuit die; positioning a mold having a body and a protrusion extending outwardly therefrom on the integrated circuit die so that the protrusion contacts a portion of the integrated circuit die; and positioning encapsulating material within the mold and surrounding the integrated circuit die. The method also preferably includes the step of removing the mold including the protrusion to define an opening through the body of encapsulating material to thereby expose a portion of the integrated circuit die.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of an integrated circuit fingerprint sensor in combination with a notebook computer in accordance with the present invention.

FIG. 2 is a schematic diagram of an integrated circuit fingerprint sensor in combination with a computer workstation and associated information processing computer and local area network (LAN) in accordance with the present invention.

FIG. 3 is a schematic perspective view of an embodiment of an integrated circuit fingerprint sensor in accordance with the invention.

FIG. 4 is a schematic plan view of a portion of the integrated circuit fingerprint sensor and an overlying finger-print pattern in accordance with the present invention with a portion thereof greatly enlarged for clarity of illustration.

FIG. 5 is a greatly enlarged plan view of a portion of the integrated circuit fingerprint sensor in accordance with the invention with the upper dielectric layer removed therefrom for clarity of illustration.

FIG. 6 is a schematic perspective view of a portion of the integrated circuit fingerprint sensor in accordance with the present invention.

FIG. 7 is a schematic fragmentary view of a portion of the integrated fingerprint sensor in accordance with the present invention.

FIG. 8 is a schematic side view, partially in section, illustrating the electric fields in accordance with the present invention.

FIG. 9 is a schematic circuit diagram of a portion of the integrated fingerprint sensor in accordance with the present invention.

FIG. 10 is an enlarged schematic side view, partially in section, further illustrating the electric fields in accordance with the present invention.

FIG. 11 is a slightly enlarged schematic cross-sectional view taken along lines 11—11 of FIG. 3.

FIG. 12 is a greatly enlarged schematic cross-sectional view of a portion of an alternate embodiment of an integrated circuit device according to the invention.

FIG. 13 is a greatly enlarged schematic cross-sectional view of a contact pad portion in an embodiment of the integrated circuit device according to the invention.

FIG. 14 is a greatly enlarged schematic cross-sectional view of a portion of an alternate embodiment of an integrated circuit device according to the invention.

FIG. 15 is a plan view of an integrated circuit fingerprint sensing device incorporated into a carrying card in accordance with the present invention.

FIGS. 16–18 are schematic cross-sectional views of the integrated circuit device during manufacturing in accordance with a method of the present invention.

FIGS. 19 and 20 are schematic cross-sectional views of the integrated circuit device during another manufacturing process in accordance with a method of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime and multiple prime notation is used in alternate embodiments to indicate similar elements. The scaling of various features, particularly fingers and layers in the drawing figures, have been exaggerated for clarity of explanation.

Referring first to FIGS. 1–3, an integrated circuit fingerprint sensor 30 in accordance with the invention is initially described. The illustrated fingerprint sensor 30 includes a housing or package 51, a dielectric layer 52 exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of signal conductors or leads 53. A conductive strip or electrode 54 around the periphery of the dielectric layer 52 may also provide a contact electrode for the finger as described in greater detail below. The sensor 30 may provide output signals in a range of sophistication levels depending on the level of processing incorporated in the package as also described in greater detail below.

The integrated circuit fingerprint sensor 30 may be used in many different applications as will be readily appreciated by those skilled in the art, such as for personal identification or verification purposes. For example, the sensor 30 may be used to permit access to a computer workstation, such as a notebook computer 35 including a keyboard 36 and associated folding display screen 37 (FIG. 1). In other words, user access to the information and programs of the notebook computer 35 may only be granted if the desired or previously enrolled fingerprint is first sensed as also described in greater detail herein.

Another application of the fingerprint sensor 30 is illustrated with particular reference to FIG. 2. The sensor 30 may be used to grant or deny access to a fixed workstation 41 for a computer information system 40. The system may include a plurality of such workstations 41 linked by a local area network (LAN) 43, which in turn, is linked to a fingerprint identification server 43, and an overall central computer 44. Many other applications for the low cost and reliable electric field sensor 30 in accordance with the invention are con-

templated by the invention and will be readily appreciated by those skilled in the art.

Referring now additionally to FIGS. 4–10, the fingerprint sensor 30 in accordance with one aspect of the invention is described in greater detail. The fingerprint sensor 30 includes a plurality of individual pixels or sensing elements 30a arranged in array pattern as shown perhaps best in FIGS. 4 and 5. As would be readily understood by those skilled in the art, these sensing elements are relatively small so as to be capable of sensing the ridges 59 and intervening valleys 60 of a typical fingerprint (FIG. 4). As will also be readily appreciated by those skilled in the art, live fingerprint readings as from the electric field sensor 30 in accordance with the present invention may be more reliable than optical sensing, because the conduction of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate with a fingerprint image on a substrate or even with a three-dimensional model of a fingerprint, for example.

The fingerprint sensor 30 includes a substrate 65, and one or more active semiconductive layers 66 thereon. In the illustrated embodiment a ground plane electrode layer 68 is above the active layer 66 and separated therefrom by an insulating layer 67. A drive electrode layer 71 is positioned over another dielectric layer 70 and is connected to an excitation drive amplifier 74. The excitation drive signal may be typically in the range of about 1 KHz to 1 MHz and is coherently delivered across all of the array. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor 30 may be reduced, while the reliability is increased.

Another insulating layer 76 is on the drive electrode layer 71, and an illustratively circularly shaped sensing electrode 78 is on the insulating layer 76. The sensing electrode 78 may be connected to sensing electronics 73 formed in the active layer 66 as schematically illustrated, and as would be readily appreciated by those skilled in the art.

An annularly shaped shield electrode 80 surrounds the sensing electrode 78 in spaced relation therefrom. As would be readily appreciated by those skilled in the art the sensing electrode 78 and its surrounding shield electrode 80 may have other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements 30a. The shield electrode 80 is an active shield which is driven by a portion of the output of the amplifier circuit 73 to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electrodes. Accordingly, the sensor 30 permits all of the sensing elements to be driven by a coherent drive signal in sharp contrast to prior art sensors which required that each sensing electrode be individually driven.

As understood with additional reference to FIGS. 8–10, the excitation electrode 71 generates a first electric field to the sensing electrode 78 and a second electric field between the sensing electrode 78 and the surface of the finger 79, over the distances d1 and d2, respectively. In other terms, a first capacitor 83 (FIG. 9) is defined between the excitation electrode 71 and the sensing electrode 78, and a second capacitor 85 is defined between the finger skin 79 and ground. The capacitance of the second capacitor 85 varies depending on whether the sensing electrode 78 is adjacent a fingerprint ridge or valley. Accordingly, the sensor 30 can be modeled as a capacitive voltage divider. The voltage sensed by the unity gain voltage follower or amplifier 73 will change as the distance d2 changes.

In general, the sensing elements 30a operate at very low currents and at very high impedances. For example, the

output signal from each sensing electrode 78 is desirably about 5 to 10 millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element 30a, as defined by the outer dimensions of the shield electrode 80, may be about 0.002 to 0.005 inches in diameter. The excitation dielectric layer 76 and surface dielectric layer 52 may desirably have a thickness in the range of about 1 μm . The ground plane electrode 68 shields the active electronic devices from the excitation electrode 71. A relatively thick dielectric layer 67 will reduce the capacitance between these two structures and thereby reduce the current needed to drive the excitation electrode. The various signal feedthrough conductors for the electrodes 78, 80 to the active electronic circuitry may be readily formed as would be understood by those skilled in the art. In addition, the illustrated signal polarities may be readily reversed as would also be readily understood by those skilled in the art.

The overall contact or sensing surface for the sensor 30 may desirably be about 0.5 by 0.5 inches—a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor 30 in accordance with the invention is also fairly tolerant of dead pixels or sensing elements 30a. A typical sensor 30 includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor 30 may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

Turning now additionally to FIG. 11 the packaging of the fingerprint sensor 30 is further described. As would be readily understood by those skilled in the art, an integrated circuit fingerprint sensor presents a special packaging difficulty since it has to be touched by the finger being scanned or sensed. It is typically desired to avoid touching of an integrated circuit in conventional integrated circuit fabrication, in part, because of potential contamination. The main contaminants of concern may be sodium and the other alkaline metals. These ionic contaminants have very high mobility in the SiO_2 layers that are typically used to passivate the integrated circuit. The resulting oxide charge may degrade device characteristics especially in MOS technology.

One conventional approach to controlling mobile ionic contamination uses hermetic packaging with a phosphorus-doped passivation layer over the integrated circuit. The phosphorus doping reduces contaminant mobility by trapping mechanisms as would be readily understood by those skilled in the art. Plastic packaging has now become more widespread, and a silicon nitride or silicon carbide passivation layer may be used with the plastic packaging. Silicon nitride or silicon carbide may greatly reduce the permeability to contaminants to permit direct contact between the finger of the user and the integrated circuit. Accordingly, silicon nitride or silicon carbide may preferably be used as an outermost passivation layer of the fingerprint sensor 30 in accordance with an embodiment of the present invention.

An integrated circuit device, such as the fingerprint sensor 30, also raises several unique packaging requirements including: the package needs to be open to enable finger-to-sensor die contact; the package should be physically strong in order to withstand rough use; the package and die should be able to withstand repeated cleaning with detergent and/or disinfectant solutions, and including scrubbing; the die should be able to withstand contact with a wide variety of organic and inorganic contaminants, and should be able to

withstand abrasion; and finally the package should be relatively inexpensive.

The illustrated package 51 addresses these packaging issues. The package 51 includes an integrated circuit die 91 mounted on a lead frame 93 during injection molding to form the body 94 of encapsulating material of the package. Connections are made by bond wires 97 and the lead frame 93 to the outwardly extending leads 53 as would be readily understood by those skilled in the art. The upper surface of the package 51 includes an integrally molded opening 98 which direct permits contact to the die 91. More particularly, the opening 98 is defined in the illustrated embodiment by a frame member or electrically conductive member which serves as an electrode 54. The electrode 54 is illustratively connected to the underlying portion of the die 91 by an electrically conductive adhesive 95 which provides advantages in manufacturing of the sensor 30 as explained in greater detail below.

The inner exposed sides of the electrode 54 may be slightly angled as shown in the illustrated embodiment. As also shown in the illustrated embodiment, the frame member or electrode 54 is mechanically held in position within the body 94 of surrounding encapsulating material by an interlocking fit between a tongue of plastic material and a corresponding groove in the electrode. Of course, those of skill in the art will recognize other arrangements of interlocking means at the interface between the body 94 and the electrode 54.

As will be readily appreciated by those skilled in the art, the electrode 54 may be advantageously interconnected to circuitry within the integrated circuit die 91. In particular with reference additionally to FIG. 12, a conductor filled via 104 may be used to connect to the electrode 54. As also shown in FIG. 12, an alternate mechanical locking arrangement is illustrated at the interface between the body 94' of encapsulating material and the electrode 54'. The illustrated electrode 54' has an L-shaped cross-section and those of skill in the art will readily appreciate that other cross-sectional shapes are possible and are contemplated by the present invention.

In addition, FIG. 12 illustrates an embodiment of the invention wherein the electrode 94' is set back from the opening 98'. More particularly, a strut 105 may be used to hold a body of removable material to form the opening during molding as described in greater detail below. In other words, one or more struts 105 may define a space between the frame member or electrode 54' and the body of removable material during molding. Accordingly, an inner portion of plastic 94a is formed interior of the electrode 54' during injection molding.

Yet another advantageous feature illustrated in FIG. 12 relates to clamping a voltage at the electrode 54'. More particularly, an electrostatic voltage on the user's finger, if not properly dissipated, may damage components of the integrated circuit die 91' as would be readily understood by those skilled in the art. In addition, a voltage imparted to the electrode 54' from the drive circuitry 109 should desirably not exceed a predetermined level to avoid accidental shocking of the user. Accordingly, the invention advantageously includes the illustrated voltage clamping circuit 108 provided by the illustrated pair of zener diodes 111 and resistor 112. Those of skill in the art will readily appreciate that other clamping circuits are also contemplated by the present invention.

As would be readily appreciated by those skilled in the art, in certain embodiments of the fingerprint sensor or other

integrated circuit devices a ground electrode may not be necessary, as the body may serve as a large capacitor itself for the fingerprint sensor. However, the illustrated electrode 54' may still advantageously provide a conductor for contacting the finger to dissipate static discharge in cooperation with the clamping circuit 109. As discussed elsewhere herein, in yet other embodiments of the invention, the electrode 54 may not be needed in the final integrated circuit device.

Referring now additionally to FIG. 13 another aspect of the invention is explained. Additional bonding pad protection may be provided in certain embodiments of the invention. In the illustrated structure, a bonding pad 120 of aluminum, for example, is formed on an outer surface of the die. A first passivating layer 122 is formed over the upper die surface and covering edge portions of the bond pad 120. A second and preferably thicker passivating layer 123 is applied over the first passivating layer 122. A barrier metal layer 124 is formed on the opening in the second layer 123 and contacts the underlying aluminum bond pad 120. The barrier metal may be an alloy comprising regions of titanium/tungsten; titanium/tungsten nitride; and titanium/tungsten to protect the underlying relatively corrosion susceptible aluminum. A gold layer 126 may be formed over the barrier metal layer 124, and a bond wire 97" connected thereto as would be readily appreciated by those skilled in the art. Those of skill in the art will also readily appreciate other similar structures for protecting the susceptible bond pads 120 from corrosion or degradation as when exposed to water or other contaminants.

The outer passivation layer 123 may comprise silicon nitride for the reasons highlighted above. In addition, another protective coating comprising an organic material, such as polyimide or PTFE (Teflon™) may be provided which yields advantages in wear resistance and physical protection. Inorganic coatings, such as silicon carbide or amorphous diamond, may also be used for the outer layer 123 and may greatly enhance wear resistance, especially to abrasive particles. In addition, the material of the outer passivation layer 123 is preferably compatible with standard integrated circuit pattern definition methods in order to enable bond pad etching, for example.

Yet another significant aspect of the invention understood with reference to FIG. 13 is that the integrated circuit die 91" may include a plurality of metal layers 131 and intervening dielectric layers 130 supported on a relatively rigid silicon substrate 132. Conventional annealed aluminum is typically relatively soft and is deposited with a relatively large thickness. Accordingly, one aspect of the present invention is that the metal layers 131 may be provided by a refractory metal or alloys thereof which may be relatively thin and which are relatively rigid. For example, the refractory metal may include tungsten, molybdenum, titanium or alloys thereof. Other refractory metals, and other non-refractory metals may also be used as long as they are relatively rigid and may be formed in a relatively thin layer. For example, for CVD tungsten the thickness is preferably more than about 0.1 μm and preferably less than about 1.0 μm . Considered another way, the metal layers are preferably devoid of aluminum. Thus, the integrated circuit die 91" is more robust to resist damage as may be caused by direct physical contact with a finger of the user, for example.

Those of skill in the art will readily appreciate that the bond pad sealing means disclosed herein and as illustrated in FIG. 13 may be advantageously used in combination with the interface sealing provided by the adhesively secured electrode 54. Those of skill in the art will also recognize that

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the bond pad sealing means may also be used by itself in certain embodiments, such as shown in FIG. 14 wherein no electrode remains adjacent the opening 98" for either the full extent of the interface or only a part thereof. As also illustrated in FIG. 14, corrosion sensing means 135 may be provided to enable control logic on the integrated circuit die 91"" or remote therefrom to detect corrosion, before failure of the bond pads or other portions of the encapsulated device. The corrosion sensing means 135 may be provided by a resistance network which is periodically monitored for a change in value as would be readily understood by those skilled in the art.

Another variation of the fingerprint sensor 30"" is illustrated in FIG. 15 wherein the integrated circuit die is encapsulated within plastic material defining a card 139 for carrying by the user. The illustrated sensor 30"" includes only a single electrode portion 54"" extending along only a portion of the generally rectangular opening. In other embodiments as discussed above, the electrode or frame member may define a closed geometric shape, such as a rectangle. The card 139 may include the illustrated magnetic stripe 138 for carrying data, for example, and which operates in conjunction with the fingerprint sensor 30"" as would also be readily understood by those skilled in the art. The card 139 may also carry one or more other integrated circuit dies to enable data processing and storage, for example, as would also be understood by those skilled in the art.

The method aspects of the invention are now explained with reference to FIGS. 16–18. As shown in FIG. 16, an assembly 150 including the electrode 54, a body 151 of removable material, and an adhesive layer 95 on the underside of the electrode is aligned over and positioned onto the integrated circuit die 91 which, in turn, has been secured and connected to the lead frame 93. The thus formed structure is positioned within a conventional integrated circuit package injection mold 160 (FIG. 17) and the body 94 of encapsulating plastic material is formed as would be readily understood by those skilled in the art. As shown in FIG. 18, after removal from the injection mold 160, the structure is positioned in a bath 165 containing a liquid solvent 166, such as water, for example, so that the body of removable material is dissolved away leaving the opening 98 to the underlying portion of the integrated circuit die 91. Those of skill in the art will appreciate many materials that may be readily removed to define the opening. In addition, a solvent spray may be used to dissolve the removable material.

Turning now additionally to FIGS. 19 and 20 another method in accordance with the invention for making the integrated circuit device 30"" (FIG. 14) is now described. In this embodiment, an upper mold portion 171 includes a body 173 and a protrusion 172 extending downwardly therefrom. The upper mold portion 171 is brought together with the lower mold portion 174, and plastic encapsulating material 941"" is injected into thus defined mold cavity as shown in FIG. 20. As would be readily understood by those skilled in the art, the protrusion 172 may be hollow rather than solid as shown in the illustrated embodiment. The other elements are indicated with a triple prime and are similar to those described above.

Provisions may be made to ensure biasing of the protrusion 172 against the integrated circuit die 91 during injection molding as would also be readily understood by those skilled in the art. The upper and lower mold portions may be parted to free the integrated circuit device 30"".

As will be readily appreciated by those skilled in the art, the techniques and structures for defining and sealing an

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opening to the surface of an integrated circuit die may be used for many integrated circuit devices. The invention is particularly applicable to a fingerprint sensor 30 wherein direct contact with the finger of the user is performed. The invention may also be used for other sensors, such as gas or liquid sensors, wherein direct exposure of the integrated circuit die to the sensed medium is desirable and wherein other portions of the die are desirably protected from such exposure.

The various embodiments of the fingerprint sensor 30 and its associated processing circuitry may implement any of a number of conventional fingerprint matching algorithms. For example, a suitable fingerprint matching algorithm and indexing approach for quick and efficient searching is described in copending patent application entitled "Methods and Related Apparatus for Fingerprint Indexing and Searching", having Ser. No. 08/589,064, assigned to the assignee of the present invention and the entire disclosure of which is incorporated herein by reference in its entirety.

As would be readily understood by those skilled in the art, fingerprint minutiae, that is, the branches or bifurcations and end points of the fingerprint ridges, are often used to determine a match between a sample print and a reference print database. Such minutiae matching may be readily implemented by the processing circuitry of the present invention as would be readily understood by those skilled in the art. For example, U.S. Pat. Nos. 3,859,633 and 3,893,080 both to Ho et al. are directed to fingerprint identification based upon fingerprint minutiae matching. U.S. Pat. No. 4,151,512 to Riganati et al., for further example, describes a fingerprint classification method using extracted ridge contour data. U.S. Pat. No. 4,185,270 to Fischer II et al. discloses a process for encoding and verification also based upon minutiae. In addition, U.S. Pat. No. 5,040,224 to Hara discloses an approach to preprocessing fingerprints to correctly determine a position of the core of each fingerprint image for later matching by minutiae patterns. The entire disclosures of each of these U.S. patents are incorporated herein by reference.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A fingerprint sensing device comprising:
an integrated circuit die comprising a first fingerprint sensing portion for direct contact by a finger of a user, and a second surface portion opposite the first fingerprint sensing portion;
an integrally molded body of encapsulating material surrounding said integrated circuit die including the second surface portion thereof, said body of encapsulating material having an opening therein exposing the first fingerprint sensing portion of said integrated circuit die to adjacent a periphery of the first fingerprint sensing portion to permit direct contact by the finger of the user with the first fingerprint sensing portion; and
an electrically conductive member being mounted to said body of encapsulating material adjacent the opening therein and adjacent the first fingerprint sensing portion so that the finger of the user directly contacts the electrically conductive member as the finger is positioned onto the first fingerprint sensing portion.

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2. A fingerprint sensing device according to claim 1 wherein said electrically conductive member is positioned so as to define at least a portion of a frame for the opening in said body of encapsulating material.

3. A fingerprint sensing device according to claim 1 wherein said electrically conductive member has a closed geometric shape.

4. A fingerprint sensing device according to claim 1 wherein said electrically conductive member has a generally rectangular shape.

5. A fingerprint sensing device according to claim 1 further comprising interconnection means for electrically connecting said electrically conductive member to said integrated circuit die.

6. A fingerprint sensing device according to claim 5 wherein said interconnection means comprises:

an electrically conductive adhesive between said electrically conductive member and said integrated circuit die;

at least one via in said integrated circuit die; and
electrically conductive material in said at least one via.

7. A fingerprint sensing device according to claim 1 wherein said first fingerprint sensing portion comprises an electric field fingerprint sensor.

8. A fingerprint sensing device according to claim 7 wherein said electric field fingerprint sensor comprises:

an array of electric field sensing electrodes;

a dielectric layer adjacent said electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto; and

drive means for applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image signal.

9. A fingerprint sensing device according to claim 1 further comprising voltage clamping means operatively connected to said electrically conductive member for clamping a voltage thereof.

10. A fingerprint sensing device according to claim 1 further comprising electrostatic discharge means for reducing an electrostatic charge of a user as the finger of the user touches said electrically conductive member.

11. A fingerprint sensing device according to claim 1 wherein said integrated circuit die further comprises a plurality of bond pads, and wherein said body of encapsulating material covers said plurality of bond pads.

12. A fingerprint sensing device according to claim 11 further comprising bond pad sealing means for protecting said plurality of bond pads from corrosion.

13. A fingerprint sensing device according to claim 12 wherein each of said bond pads comprises a first metal layer, and wherein said bond pad sealing means comprises a barrier metal layer on said first metal layer.

14. A fingerprint sensing device according to claim 13 wherein said bond pad sealing means further comprises a layer of gold on said barrier metal layer.

15. A fingerprint sensing device according to claim 1 wherein said integrated circuit die comprises:

a relatively rigid substrate; and

a plurality of metal layers on said substrate and being relatively thin and relatively rigid to provide strength to said integrated circuit die.

16. A fingerprint sensing device according to claim 15 wherein each of said plurality of metal layers comprises a refractory metal.

17. A fingerprint sensing device according to claim 15 wherein each of said plurality of metal layers is devoid of aluminum.

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18. A fingerprint sensing device according to claim 1 further comprising a lead frame connected to said integrated circuit die.

19. A fingerprint sensing device according to claim 1 wherein said electrically conductive member comprises metal.

20. A fingerprint sensing device according to claim 1 wherein said integrated circuit die comprises an outermost passivating layer.

21. A fingerprint sensing device according to claim 20 wherein said outermost passivating layer comprises at least one of a nitride, carbide, and diamond.

22. A fingerprint sensing device according to claim 1 further comprising an adhesive layer between said integrated circuit die and said electrically conductive member.

23. A fingerprint sensing device according to claim 1 wherein said body of encapsulating material comprises plastic.

24. A fingerprint sensing device according to claim 1 wherein said body of encapsulating material comprises injection molded plastic.

25. A fingerprint sensing device according to claim 1 further comprising locking means defined at an interface between said electrically conductive member and said body of encapsulating material for forming a mechanical lock therebetween.

26. A fingerprint sensing device according to claim 1 further comprising corrosion sensing means for sensing corrosion of said integrated circuit die.

27. A fingerprint sensing device comprising:
an integrated circuit die comprising a first fingerprint sensing portion for direct contact by a finger of a user, and a second surface portion opposite the first fingerprint sensing portion;

an integrally molded body of encapsulating material surrounding said integrated circuit die including the second surface portion thereof, said body of encapsulating material having an opening therein exposing the first fingerprint sensing portion of said integrated circuit die to adjacent a periphery of the first fingerprint sensing portion to permit direct contact by the finger of the user with the first fingerprint sensing portion; and
an electrically conductive member being mounted to said body of encapsulating material adjacent the opening therein to define at least a portion of a frame for the opening so that the finger of the user directly contacts the electrically conductive member as the finger is positioned onto the first fingerprint sensing portion.

28. A fingerprint sensing device according to claim 27 wherein said electrically conductive member has a closed geometric shape.

29. A fingerprint sensing device according to claim 27 further comprising interconnection means for electrically connecting said electrically conductive member to said integrated circuit die.

30. A fingerprint sensing device according to claim 27 further comprising voltage clamping means operatively connected to said electrically conductive member for clamping a voltage thereof.

31. A fingerprint sensing device according to claim 27 wherein said integrated circuit die further comprises a plurality of bond pads, and further comprising bond pad sealing means for protecting said plurality of bond pads from corrosion.

32. A fingerprint sensing device according to claim 27 wherein said integrated circuit die comprises:
a relatively rigid substrate; and

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a plurality of metal layers on said substrate and being relatively thin and relatively rigid to provide strength to said integrated circuit die.

33. A fingerprint sensing device according to claim **27** further comprising an adhesive layer between said integrated circuit die and said electrically conductive member.

34. A fingerprint sensing device according to claim **27** further comprising locking means defined at an interface between said electrically conductive member and body of encapsulating material for forming a mechanical lock therebetween.

35. A fingerprint sensing device comprising:

an integrated circuit die comprising a first fingerprint sensing portion for direct contact by a finger of a user, and a second surface portion opposite the first fingerprint sensing portion;

an integrally molded body of encapsulating material surrounding said integrated circuit die including the second surface portion thereof, said body of encapsulating material having an opening therein exposing the first fingerprint sensing portion of said integrated circuit die to adjacent a periphery of the first fingerprint sensing portion to permit direct contact by the finger of the user with the first fingerprint sensing portion;

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an electrically conductive member mounted to said body of encapsulating material and adjacent the first fingerprint sensing portion so that the finger of the user directly contacts the electrically conductive member; and

voltage clamping means operatively connected to said electrically conductive member for clamping a voltage thereof.

36. A fingerprint sensing device according to claim **35** wherein said voltage clamping means comprises electrostatic discharge means for reducing an electrostatic charge of a user upon the user touching said electrically conductive member.

37. A fingerprint sensing device according to claim **35** wherein said electrically conductive member is positioned so as to define at least a portion of a frame for the opening in said body of encapsulating material.

38. A fingerprint sensing device according to claim **35** wherein said electrically conductive member has a closed geometric shape.

39. A fingerprint sensing device according to claim **35** further comprising an adhesive layer between said integrated circuit die and said electrically conductive member.

* * * * *

EXHIBIT B



US006667439B2

(12) **United States Patent**
Salatino et al.

(10) **Patent No.:** US 6,667,439 B2
(b) **Date of Patent:** Dec. 23, 2003

(54) **INTEGRATED CIRCUIT PACKAGE INCLUDING OPENING EXPOSING PORTION OF AN IC**

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(73) Assignees: **Authentec, Inc.**, Melbourne, FL (US); **Hestia Technologies, Inc.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 30 days.

(21) Appl. No.: **09/931,378**

(22) Filed: **Aug. 16, 2001**

(65) **Prior Publication Data**

US 2002/0088632 A1 Jul. 11, 2002

Related U.S. Application Data

(60) Provisional application No. 60/225,972, filed on Aug. 17, 2000.

(51) **Int. Cl.** ⁷ **H01L 23/00**

(52) **U.S. Cl.** **174/52.1; 361/728; 361/752;**
257/690; 257/787

(58) **Field of Search** **174/52.1, 52.2,**
174/52.3; 361/728, 736, 748, 752; 257/678,
690, 691, 701, 777, 778, 787

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Primary Examiner—Dean A. Reichard

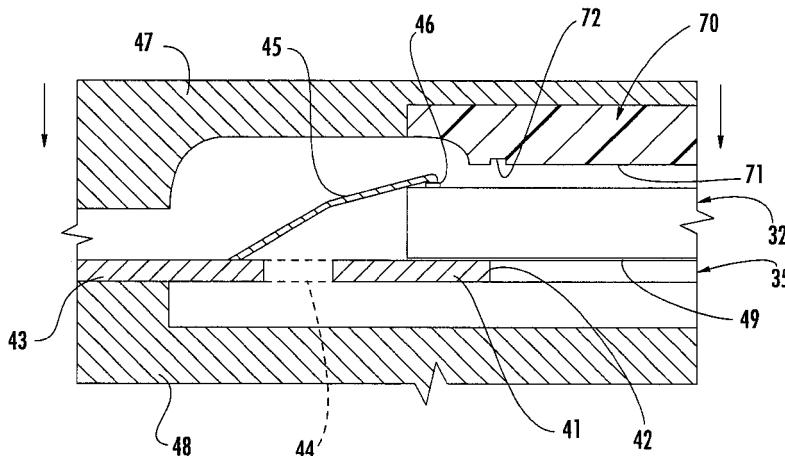
Assistant Examiner—W. David Walkenhorst

(74) **Attorney, Agent, or Firm**—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

(57) **ABSTRACT**

An IC package preferably includes an IC and encapsulating material surrounding the IC, with the encapsulating material having an opening therein to define an exposed portion of the IC. Vestigial portions of encapsulating material may be left on the exposed portion of the IC and spaced inwardly from a periphery of the opening based upon molding using a mold protrusion which includes a bleed-through retention channel positioned inwardly from peripheral edges. The channel collects and retains any bleed-through of the encapsulating material. The IC package may further include a leadframe carrying the IC. The leadframe may include a die pad, finger portions, and a plurality of die pad support bars. The die pad may be downset below a level of the finger portions. Each of the die pad support bars may be resiliently deformed to accommodate the downset of the die pad. Low stress encapsulating material and adhesive may also be included in the IC package.

58 Claims, 5 Drawing Sheets

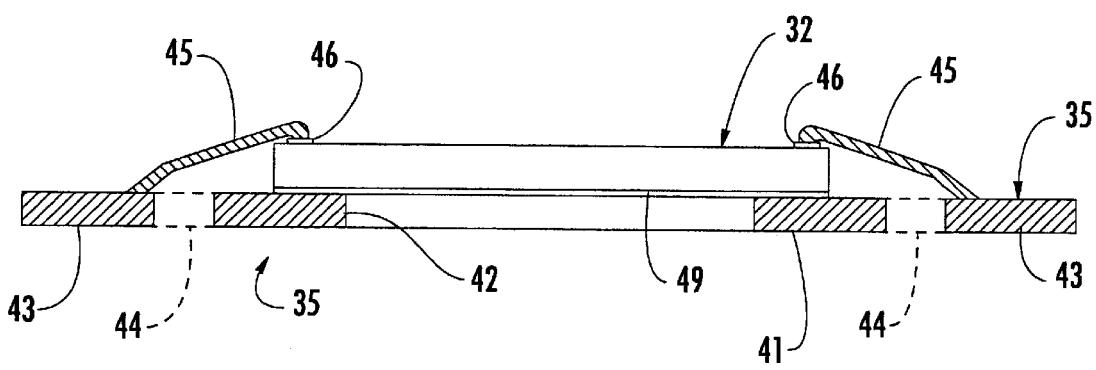
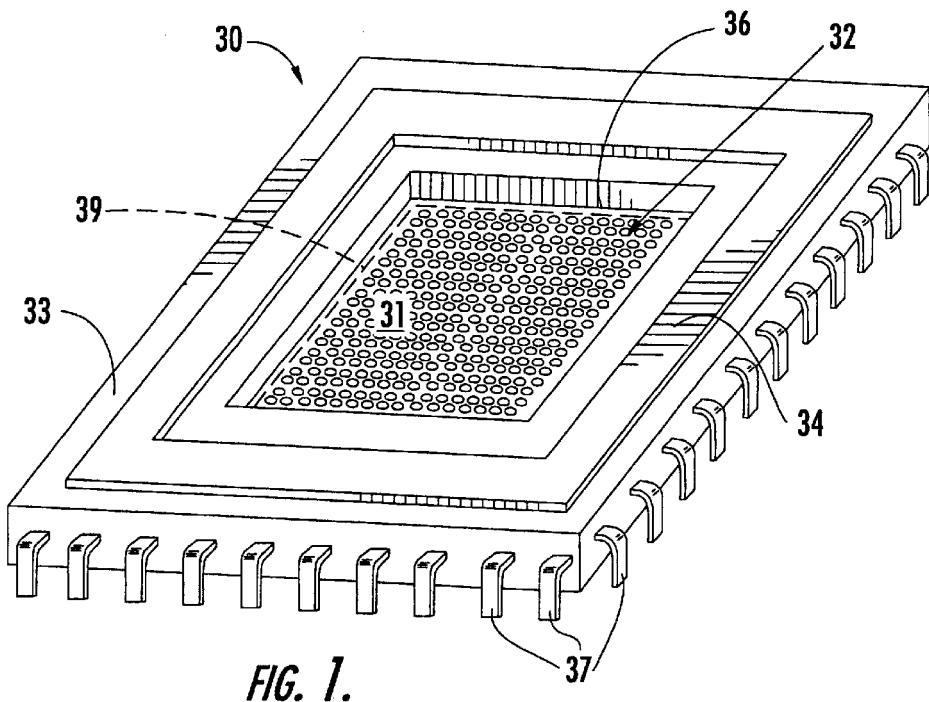


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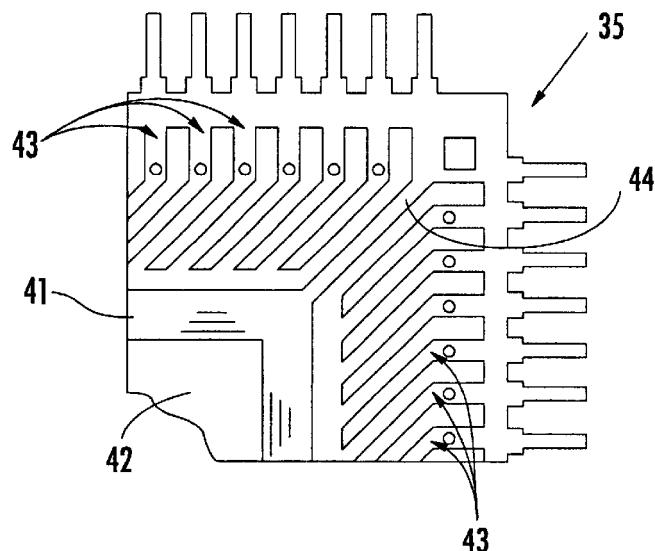


FIG. 3.

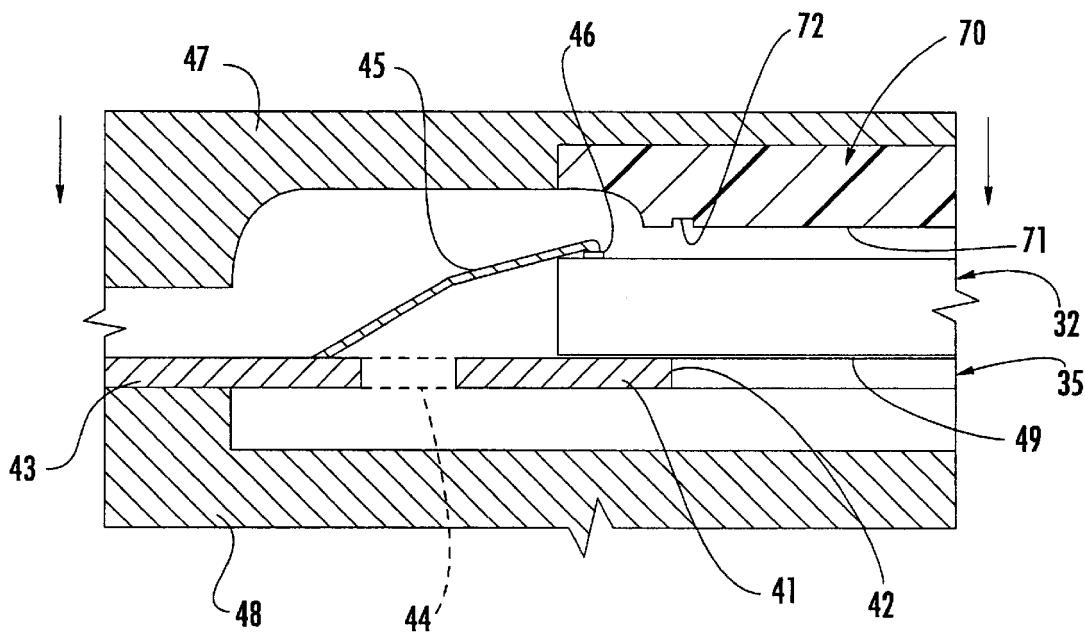


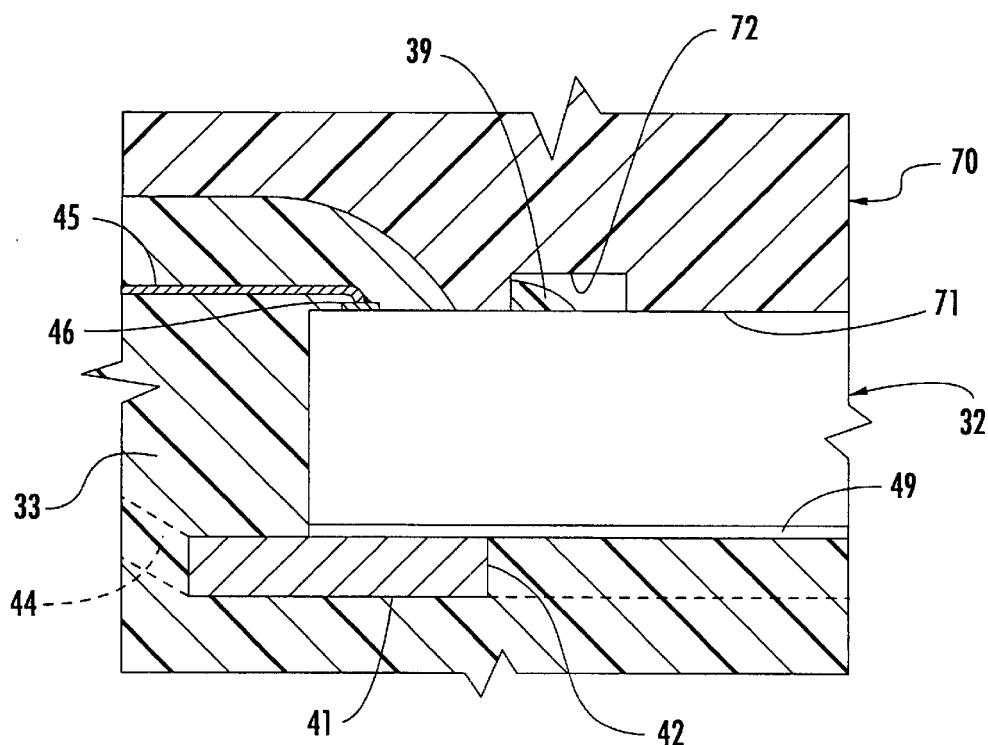
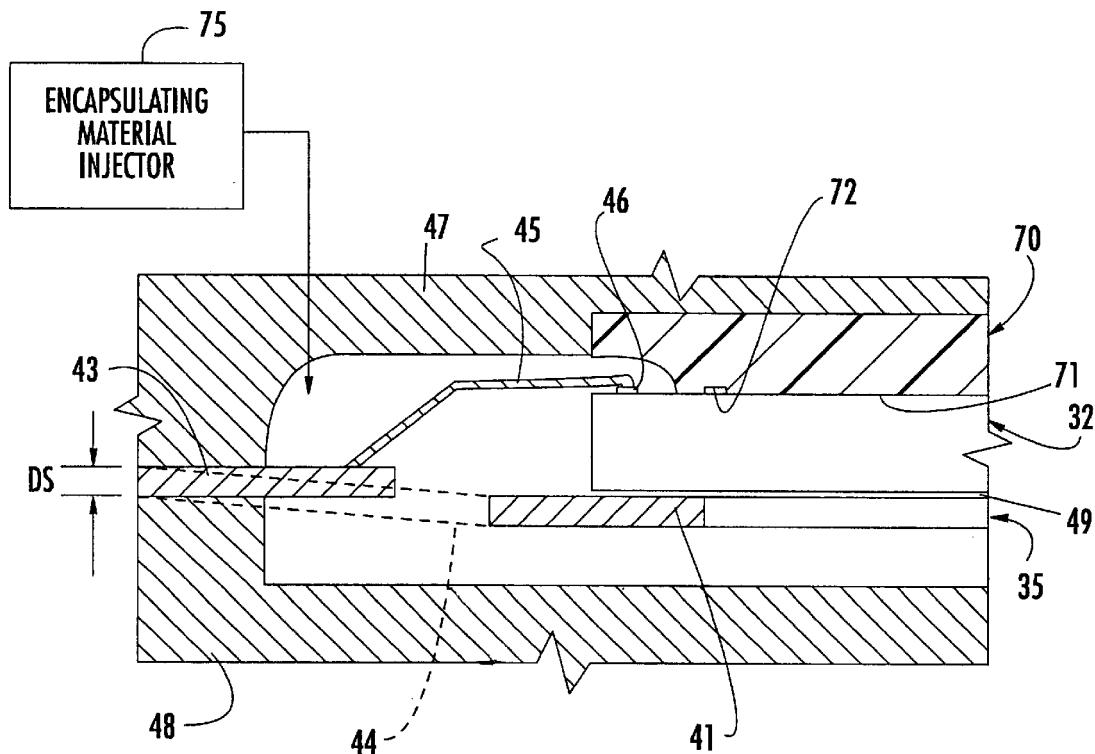
FIG. 4.

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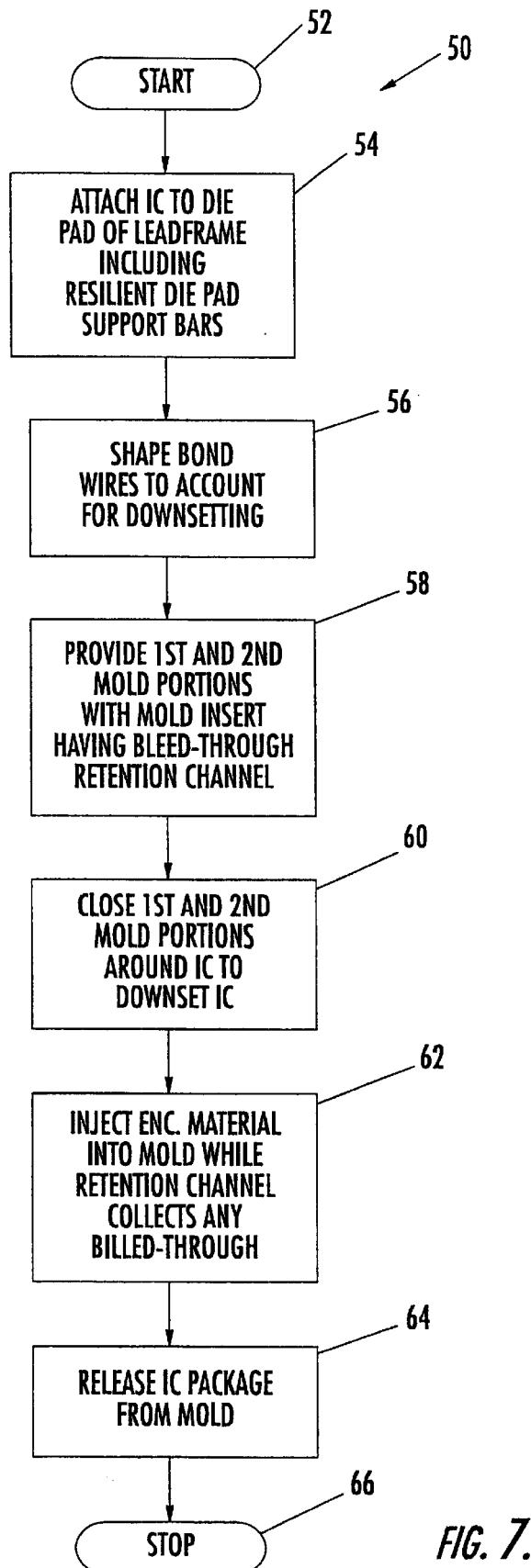


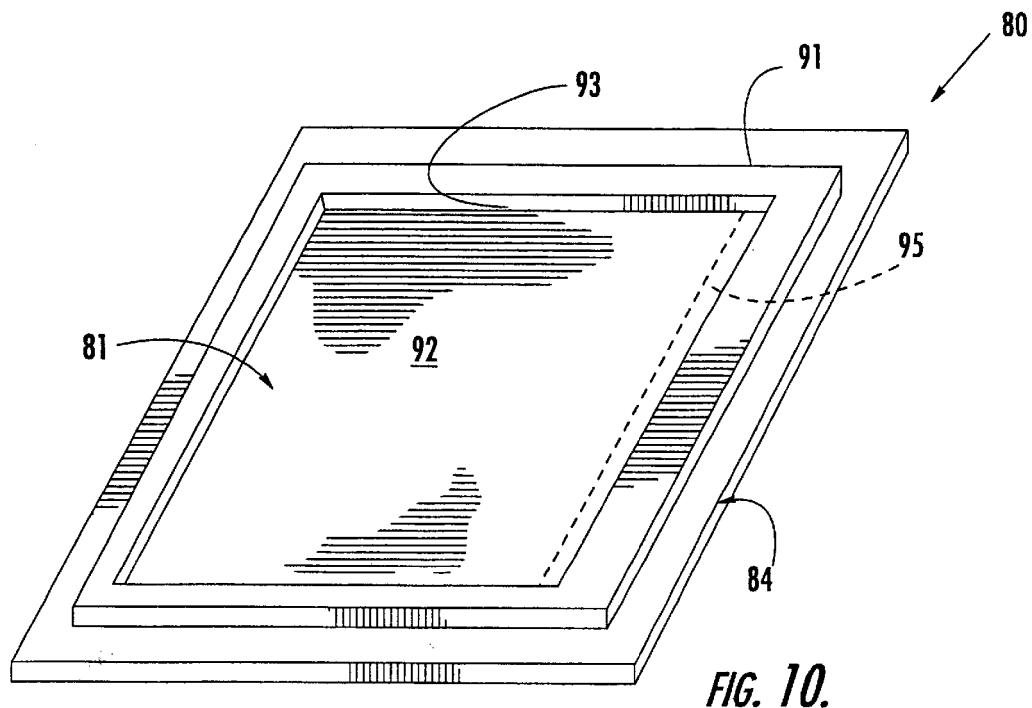
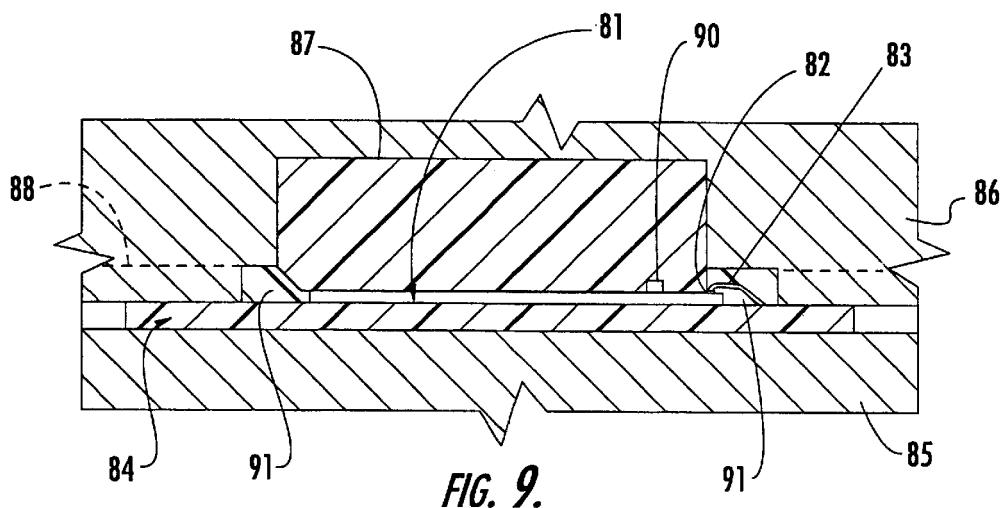
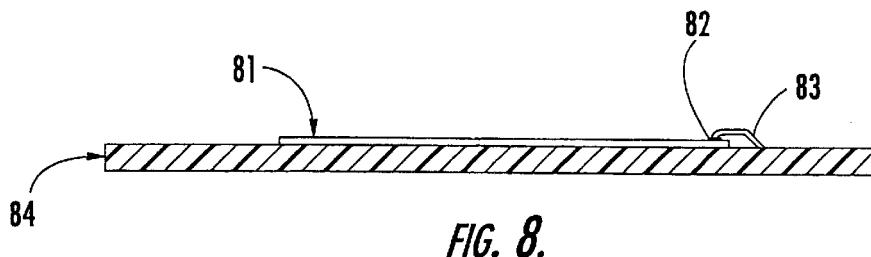
FIG. 7.

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**INTEGRATED CIRCUIT PACKAGE
INCLUDING OPENING EXPOSING
PORTION OF AN IC****RELATED APPLICATION**

This application is based upon U.S. provisional application serial No. 60/225,972 filed Aug. 17, 2000, the entire contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to the field of electronics, and, more particularly, to integrated circuit packages.

BACKGROUND OF THE INVENTION

Integrated circuit (IC) devices or packages are used in a wide variety of electronic applications including computers, cellular telephones, entertainment systems, etc. A typical IC package includes a chip of semiconductor material, or IC, in which active electronic devices are formed. Surrounding the IC is an encapsulating material, such as typically formed of a thermosetting or thermoplastic resin compound. To protect the IC from damage or contamination, the encapsulating material typically totally surrounds the IC.

The IC itself may be carried by a leadframe. The leadframe includes a die pad which carries the IC, finger portions which provide the electrical pins extending outwardly from the encapsulating material, and die pad support bars which extend from the die pad to the finger portions. Contact or bond pads on the surface of the IC are typically electrically connected to respective finger portions by bond wires which are surrounded by encapsulating material.

IC packaging has typically been concerned with protection and interconnects. Low cost, high volume manufacturing techniques are well established for conventional IC packaging. However, with the advent of various types of sensor, receiving, and/or transmitting circuits based on IC's, the need has arisen to expose some or most of the surface of the IC to the ambient environment. An example of such an IC device is an electric field fingerprint sensor, such as of the type described in U.S. Pat. No. 5,963,679 to Setlak and U.S. Pat. No. 5,862,248 to Salatino et al. Such sensors are available commercially from the assignee of these patents and the present invention, AuthenTec, Inc. of Melbourne, Fla.

The Salatino et al. patent, for example, discloses several approaches for molding the opening in the encapsulating material to expose the fingerprint sensing matrix. One approach uses a frame which holds a body of removable material in its interior and which is positioned on the IC before molding. After molding the body may be removed thereby producing the opening through the encapsulating material. In another embodiment, an upper mold includes a downward protruding portion which directly contacts the IC to exclude the encapsulating material from the surface of the IC during injection molding to thereby form the opening exposing the IC.

Somewhat similar, a number of other patents disclose forming an opening in the encapsulating material from beneath the IC. Accordingly, cooling media may be circulated in the opening, such as disclosed in U.S. Pat. No. 5,687,474 to Hamzehdoost et al. Similarly, U.S. Pat. No. 5,570,272 to Variot provides a heatsink body in the opening beneath the IC. A pressure sensor is disclosed in U.S. Pat. No. 5,424,249 to Ishibashi wherein the encapsulating material is first completely formed then an opening is cut therethrough to an underlying sensing diaphragm.

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Methods for packaging IC's with an opening therein have generally been cumbersome and expensive, such as requiring specialized pre-made packaging and flexible or rigid printed circuit boards. These approaches are not well-suited to reliable, high volume, low cost manufacturing. Indeed, despite continuing significant developments, such as those described in the above noted Salatino et al. patent, a number of challenges are still presented for an IC package that exposes a portion of the IC. For example, it may be difficult to keep encapsulating material from bleeding under a mold protrusion that contacts the IC to form the opening. Preventing crush damage to the IC from foreign particles pressed between the mold and the IC also remains a challenge. Variations in the thicknesses of the IC's, adhesive layers, leadframes, etc. as well as accommodating IC skew also remains an area of concern.

SUMMARY OF THE INVENTION

In view of the foregoing background, it is therefore an object of the invention to provide an integrated circuit package comprising an IC and encapsulating material surrounding the IC, but leaving an exposed portion, and wherein the IC package is readily manufactured.

This and other objects, features, and advantages in accordance with the present invention are provided by an integrated circuit package comprising an IC and encapsulating material surrounding the IC, with the encapsulating material having an opening therein to define an exposed portion of the IC. In one class of embodiments, in view of the manufacturing approach, vestigial portions of encapsulating material are left on the exposed portion of the IC and spaced inwardly from a periphery of the opening in the encapsulating material. This is a result of a manufacturing process using a mold protrusion to form the opening. The mold protrusion may include a bleed-through retention channel positioned inwardly from the peripheral edges of an IC-contact surface. The bleed-through retention channel collects and retains any bleed-through of the encapsulating material and prevents its spread further inwardly onto the exposed surface of the IC.

The opening in the encapsulating material may be generally rectangular. Accordingly, the vestigial portions of encapsulating material may be arranged along at least one side of an imaginary rectangle spaced inwardly from the generally rectangular opening in the encapsulating material.

In some embodiments, the IC package may further include a leadframe carrying the IC. More particularly, the leadframe may comprise a die pad, finger portions, and a plurality of die pad support bars extending between the die pad and the finger portions at the corners. The die pad may be downset below a level of the finger portions. In addition, each of the die pad support bars may be resilient deformed to accommodate the downset of the die pad.

The package may further include bond wires extending between the IC and the finger portions. These bond wires may have a desired clearance from adjacent portions of the IC and an upper surface of the encapsulating material when the die pad is downset. In other words, shaping of the bond wires is performed to account for the downset imparted during manufacturing.

To reduce stress during cooling, the die pad may have an opening therein. Further, a low stress, low modulus adhesive may be used to secure the IC to the die pad. The encapsulating material may also be a low stress encapsulating material.

In other embodiments, the IC package may include a substrate on a back surface of the IC opposite the exposed

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portion. This substrate may cover the back surface so that the encapsulating material does not extend onto the back surface. In slightly different terms, the substrate, such as a printed circuit board, provides protection for the back surface of the IC and becomes part of the package.

The IC may include upper surface portions with active devices formed therein. The exposed portion of the IC may comprise these upper surface portions. In some advantageous embodiments, the active devices may define a sensor, such as an electric field fingerprint sensor, for example. Other devices may be similarly packaged.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of an exemplary fingerprint sensor IC package in accordance with the present invention.

FIG. 2 is a schematic cross-sectional view of the IC package as shown in FIG. 1 during manufacture.

FIG. 3 is an enlarged plan view of a portion of the leadframe as shown in FIG. 2.

FIGS. 4 and 5 are schematic partial side cross-sectional views during manufacture of the IC package as shown in FIG. 1.

FIG. 6 is a greatly enlarged schematic partial side cross-sectional view of the IC package during manufacture thereof after encapsulating material has been injected into the mold.

FIG. 7 is a flowchart of the method for manufacturing the IC package as shown in FIG. 1.

FIGS. 8 and 9 are schematic cross-sectional views of another embodiment of an IC package during manufacturing thereof.

FIG. 10 is a perspective view of the IC package as shown in FIGS. 8 and 9 upon completion.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

For clarity of explanation, the present invention is explained with reference to manufacturing methods for making an IC package 30 in the illustrated form of an electric field fingerprint sensor IC package as shown in FIG. 1. The electric field fingerprint sensor IC package 30 may of the type using an electric field to sense the ridges and valleys of a fingerprint as offered by AuthenTec, Inc. of Melbourne, Fla. under the designation FingerLoc™ AF-S2™.

The IC package 30 illustratively corresponds to a JEDEC-standard 68-pin plastic lead chip carrier (PLCC) format, although other sizes, standards, and configurations are possible. The IC package 30 may be about 24 mm square, and have a height or thickness of about 3.5 mm, for example. Another exemplary package may be a 144 lead LQFP about 1.6 mm thick.

Further details on the operation of the electric field fingerprint sensor may be found in U.S. Pat. Nos. 5,963,679 and 5,862,248 mentioned above, and, the entire disclosures of which are incorporated herein by reference. Of course,

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other sensors and other devices are also contemplated by the present invention.

The IC package 30 illustratively includes an IC chip or die 32 illustratively including an IC sensor matrix 31 which is exposed through an opening 36 in the upper portion of the encapsulating material 33. Vestigial portions of encapsulating material may remain on the exposed portion of the IC 32, outside the area of the sensor matrix 31. These vestigial portions 39 are schematically indicated in FIG. 1 by the dashed line rectangle and these vestigial portions are described in greater detail below.

The IC package 30 also includes a leadframe on which the IC 32 is mounted as will be described in greater detail below. The leadframe includes a plurality of finger portions which become the visible leads or pins 37 which also extend outwardly from the sides of the encapsulating material 33 as will be appreciated by those of skill in the art. An annular drive ring 34 is provided on the upper surface of the encapsulating material 33 adjacent the opening 36 exposing the sensing matrix 31. This drive ring 34 is specific to the illustrated electric field fingerprint sensor and is not needed in all such embodiments, or in other IC packages.

For ease of explanation, the term "IC" by itself is used primarily herein for simplicity to denote the actual integrated circuit die as will be appreciated by those of skill in the art. Also for ease of explanation, the term "IC package" is used to indicate the IC 32, surrounding encapsulating material 33, leadframe 35, etc. as an entity.

Referring now additionally to the flowchart 50 of FIG. 7, and the schematic diagrams of FIGS. 2 through 5, further details of the manufacturing method and IC package 30 produced thereby are now described. From the start (Block 52), an IC 32 is attached to a die pad 41 of the leadframe 35 at Block 54. More particularly, as perhaps best understood with reference to FIGS. 2 and 3, the leadframe 35 includes a die pad 41 and finger portions 43 which are connected together at each corner by a respective resilient die pad support bar 44. As will be appreciated by those skilled in the art, the finger portions 43 are later processed to form the visible leads 37 extending outwardly from the encapsulating material 33 as shown in FIG. 1.

The die pad 41 of the leadframe 35 also illustratively has a central opening 42 therein. This opening 24 reduces stress during cooling of the encapsulating material 33 as will be described in greater detail below. A low stress, low modulus adhesive 49 may also be used to adhesively secure the IC 32 to the die pad 41 as will also be described in greater detail below.

At Block 56 the bond wires 45, which extend between respective finger portions 43 and bond pads 46 of the IC 32, are shaped to account for later downsetting. As shown best in FIGS. 2 and 4, the bond wires 45 are initially shaped so as to be angled downwardly at their upper ends. These upper ends will extend generally horizontally upon downsetting as shown best in FIGS. 5 and 6.

At Block 58 a mold is provided having first and second, or upper and lower mold portions 47, 48 as shown in FIG. 4. The first or upper mold portion 47 preferably carries a mold protrusion 70 defining an IC-contact surface 71 with peripheral edges and a bleed-through retention channel 72 positioned inwardly from the peripheral edges.

At Block 60 the upper and lower mold portions 47, 48 are closed around the IC 32. As shown in the illustrated embodiment, the IC-contact surface 71 contacts and presses directly upon the upper surface of the IC 32 and causes the IC to be downset a distance DS as shown in FIG. 5. In other

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words, the resilient die pad support bars 44 permit the IC 32 to be contacted and moved downwardly to the position as shown in FIG. 5 so that the die pad 41 is displaced below the finger portions 43. Accordingly, a close fit is provided between the IC 32 and contact surface 71 to prevent encapsulating material from bleeding extensively beneath the mold protrusion 70 and onto the surface of the IC 32, and without crushing the IC.

The downsetting also accommodates skew of the IC surface and variations in thickness of the IC 32, adhesive layer 49, and/or portions of the leadframe 35 as will be readily appreciated by those skilled in the art. Considered in somewhat different terms, the manufacturing method includes controlling pressure applied by the IC-contact surface 71 to the IC 32 when the first and second mold portions 47, 48 are closed around the IC. This may be done as shown in the illustrated embodiment by mounting the IC 32 on the leadframe 35 having resilient portions to resiliently accommodate downsetting of the IC as the IC-contact surface 71 contacts the IC. The resilient die pad support bars 44 as shown in the illustrated embodiment, for example, maintain a desired pressure placed on the IC 32 by the contact surface 71 of the mold protrusion 70 when the mold is closed. The die pad support bars 44 are placed in tension by the downsetting to provide a spring-like force or pressure to IC 32 against the contact surface 71 of the mold protrusion 70. This pressure is controlled to avoid risk of damage while reducing likelihood of bleed-through of the encapsulating material 33 beneath the contact surface 71 as will be appreciated by those skilled in the art. Considered yet in other terms, the die pad 41 is essentially allowed to float during the molding process. The die pad support bars 44 can readily accommodate tolerance variations of several thousandths of an inch and produce high quality IC packages.

The downsetting also aligns the bond wires 45 in a proper position to provide clearance from adjacent portions of the IC 32 as well as to provide clearance from the adjacent upper surface portions of the encapsulating material 33. Accordingly shorts from contact with the IC 32, or bond wires 45 being exposed through the encapsulating material 33 are avoided. As shown in the illustrated embodiment of FIG. 5, the bond wires 45 in the completed position after downsetting may have upper portions which extend generally horizontally away from the IC 32 before turning downward toward the finger portions 43 of the leadframe 35.

At Block 62 the encapsulating material 33 is injected into the mold from the schematically illustrated injector 75 under controlled pressure. Those of skill in the art will appreciate detailed construction and operation of the encapsulating material injector 33 without further discussion herein.

As can be seen perhaps best in FIG. 6, a small bead or line of encapsulating material 33 may bleed under the peripheral edges of the mold protrusion 70 and remain as a vestigial portion 39 of the encapsulating material on the exposed surface of the IC 32. As will be appreciated by those skilled in the art the relative size of the vestigial portions 39 is greatly exaggerated for clarity of illustration. In short, the bleed-through retention channel 72 retains any encapsulating material bleeding beneath the peripheral edges of the IC contact surface 71.

It has been found that a flat contact surface of a mold protrusion alone is not likely to reliably prevent the encapsulating material 33 from wicking along the interface between the contact surface 71 and the IC 32. It is also likely that typical mold clamping pressures cannot be exerted on the IC 32 without considerable risk of damage. Because the

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clamping pressure is typically lowered, the potential for bleed-through or wicking of the encapsulating material becomes more important. Accordingly, the bleed-through retention channel 72 may be considered as providing a moat to act as a natural break for the bleeding of the encapsulating material 33 during molding.

The mold protrusion 70 may comprise a resilient material, and have a generally rectangular shape having a side dimension of about 5 to 20 mm for an IC package 30 having a side dimension of about 25 mm, for example. The bleed-through retention channel 72 may be spaced inwardly from the peripheral edges a distance of about 0.2 to 0.4 mm, for example. The retention channel 72 may also have a width of about 1 mm, and a height of about 0.15 to 0.25 mm. Those of skill in the art will appreciate that other sizes are also contemplated by the present invention depending on the application and the size of the IC package.

The IC package 30, that is, the IC 32, leadframe 35, and encapsulating material 33 may be released from the mold at Block 64 before stopping at Block 66. Those of skill in the art will appreciate that other finishing steps, including trimming excess encapsulating material, and separating the finger portions, for example, are also typically performed to produce the finished IC package 30.

Another aspect of the manufacturing relates to stress relief. Stress relief may be important since the encapsulating material 33 and the IC 32 typically have different coefficients of thermal expansion (CTEs). It is noted that the leadframe 35 may also have a different CTE. Accordingly, the manufacturing method preferably includes relieving stress during cooling of the encapsulating material 33 despite the different CTEs. The IC package 30 will have an unbalance of thermal-mechanical stress because of the opening 36. This is in contrast to the balanced stress which results in a balanced compressive force experienced by an IC in a typical fully encapsulated IC.

For example, relieving the stress may comprise using a low stress encapsulating material 33. For example, the encapsulating material 33 may be a mold compound sold under the designation Plaskon SMT-B1-LV by Cookson Semiconductor Packaging Materials of Alpharetta, Ga. Those of skill in the art will appreciate that other similar mold compounds may be used as well. Alternately or additionally, stress relief may be provided by using a leadframe 35, such as illustrated and described herein, which includes the die pad 41 with the opening 42 therein. The IC 32 may also be mounted on the die pad 41 using a low stress, low modulus adhesive 49. For example, the die attach adhesive 49 may be an adhesive sold under the designation Ablebond 8340, and manufactured by Ablestick Electronics Materials and Adhesives (National Starch and Chemical Co.) of Rancho Dominguez, Calif. The low stress, low modulus adhesive 49 and/or open die pad 41 tends to decouple the IC 32 from the leadframe 35 which may typically comprise copper.

As described herein, the IC 32 may have an upper surface with active devices formed therein, such as the illustrated fingerprint sensor with the pixel element matrix 31. Of course, those of skill in the art will appreciate that the techniques described herein could also be used to expose the back or underside of an IC.

The first and second mold portions 47, 48 may each comprise a rigid material, such as hardened steel, to provide accurate dimensions and to resist abrasion from the encapsulating material 33. Although the molding process is relatively clean, small particles may be left on the top of the IC

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32 or on the contact surface 71 of the mold protrusion 70 as will be readily appreciated by those skilled in the art. In contrast to the mold portions 47, 48, the mold protrusion 70 may comprise a compliant or resilient material so that any contaminants are not forced into the IC 32 causing damage. The material properties of the mold protrusion 70 are desirably such that any small particles will be pressed into the contact surface 71 instead of into the IC 32. However, it is still desired that the mold protrusion 70 retain its shape through the molding process. The mold tooling is also preferably such as to permit removal of the mold protrusion 70 for cleaning and/or replacement if worn or damaged as will also be appreciated by those skilled in the art.

One attribute of the molding process is that the mold will acquire a build-up of encapsulating material and wax material that may produce aesthetic problems in the finished IC package. Accordingly, mold cleaning is typically performed at periodic intervals. A conventional mold cleaning process entails molding a plastic gettering material, such as melamine, that will adhere to any organic material. After a few molding cycles using the gettering material, normal production is continued. The melamine has a high adhesion to organic particles, but low adhesion to hardened steel mold surfaces.

The mold protrusion 70 can be made of any of a number of appropriate materials. If the mold protrusion 70 is formed of an organic polymer, precautions may be needed to clean the mold, as the conventional melamine cleaning process could potentially damage the compliant mold protrusion by sticking to it and pulling it apart. Several approaches may be used to alleviate this potential difficulty. The organic polymer mold protrusion 70 can be temporarily replaced with a corresponding metal insert during melamine cleaning, for example. A metal or non-stick cap or non-stick coating could be provided over the organic polymer mold protrusion 70.

Returning again to FIGS. 1 through 6, it can be appreciated that the IC package 30 produced using the advantageous processes described herein will have certain distinguishing features and characteristics. For example, in one class of embodiments, in view of the manufacturing approach, vestigial portions 39 of encapsulating material 33 are left on the exposed portion 31 of the IC 32 and spaced inwardly from a periphery of the opening 36 in the encapsulating material. Of course, these vestigial portions 39 could be removed in some embodiments if desired, but simpler and less expensive manufacturing is obtained if the vestigial portions do not effect IC operation and are, therefore, allowed to remain on the IC 32.

As described herein, the opening 36 in the encapsulating material 33 may be generally rectangular. For these embodiments the vestigial portions 39 of encapsulating material are arranged along an imaginary rectangle spaced inwardly from the generally rectangular opening in the encapsulating material. It should be noted that the vestigial portions 39 need not necessarily be connected to form a complete rectangle, rather, the vestigial portions may be spaced, but lie along an imaginary rectangle as defined by the bleed-through retention channel 72 of the mold protrusion 70. For example, the vestigial portions may be spaced inwardly a distance of from 0.1 to 3 mm for an IC package having side dimensions of about 25 mm. Of course, the same principles can be readily applied to other polygonal, round, or other closed geometric shapes as will be appreciated by those skilled in the art.

Another characteristic of the IC package 30 resulting from manufacture as described herein is the downset relationship of the die pad 41 relative to the finger portions 43. The die

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pad support bars 44 may also be resiliently deformed to accommodate the downset of the die pad 41. In addition, the bond wires 45 will also likely have a desired clearance from adjacent portions of the IC 32 and an upper surface of the encapsulating material 33 when the die pad 41 is downset.

As also described herein, to reduce stress during cooling, the die pad 41 (FIG. 3) may have an opening 42 therein. Further, a low stress, low modulus adhesive 49 may be used to secure the IC to the die pad 41. The encapsulating material 33 may also be a low stress encapsulating material.

The IC 32 may include upper surface portions with active devices formed therein, such as fingerprint sensing circuitry. The exposed portion of the IC may comprise these upper surface portions. In some advantageous embodiments, the active devices may define a sensor, such as an electric field fingerprint sensor, for example. Other devices may be similarly packaged as will be also readily understood by those skilled in the art.

Turning now additionally to FIGS. 8–10, another embodiment of an IC package 80 and its method of manufacture are now described. As shown in FIG. 8, the IC 81 is adhesively secured to a substrate 84, which may be a printed circuit board, for example. For clarity of explanation, the layer of adhesive is not shown, but may be of the type described above, for example. The substrate 84 may be rigid in some embodiments, but can also be flexible in other embodiments. The substrate 84 may be a ball grid array substrate, or be of the type that with further processing will become a ball grid array substrate. Other substrate types are also contemplated by the invention. In other words, in this IC package 80 the leadframe 35 for mounting the IC and described extensively above is replaced with the substrate 84.

In the illustrated embodiment, the bond pads 82 are also along only one side of the IC 81, and, accordingly, the bond wires 83 are also along only one side of the IC 81. Those of skill in the art will recognize that in other embodiments, the bond pads 82 could be along two, three or all four sides in other embodiments.

The IC 81 and substrate 84 are placed between a lower mold portion 85 and an upper mold portion 86 as shown in FIG. 9, and encapsulating material 91 is injected under controlled pressure. A mold protrusion 87 is provided adjacent the upper mold portion 86. The mold protrusion 87 is desirably relatively compliant so as not to crush foreign particles into the IC 81. Further, in this embodiment, since downsetting of a leadframe 35 is not used to accommodate variations in thicknesses, the compliancy of the mold protrusion 87 accommodates any variations, such as in the thickness of the substrate 84, adhesive layer and/or IC 81. In one example, the mold protrusion 87 may comprise a solid body of Teflon, for example. As will be seen below, because there is no encapsulating material 91 injected under pressure beneath the IC 81, a more compliant mold protrusion 87 may be used than compared, for example, to the embodiments described above using the leadframe 35.

The upper mold portion 86 may be provided as two portions which mate at the illustrated dashed line 88. In other words the upper mold portion 86 may include a changeable cavity plate at the level of the dashed line 88 so that this plate may be changed to accommodate different sized packages as will be appreciated by those skilled in the art.

In this illustrated embodiment, it is further noted that the bleed-through retention channel 90 in the mold protrusion 87 is only along the right hand side of the IC 81. This is so because the encapsulating material 91 will extend onto the

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upper surface of the IC 81 to cover the bond pads 82 and bond wires 83 on the right hand side. On the lefthand side it can be seen that the encapsulating material 91 does not extend onto the upper surface, and bleed through of the encapsulating material can be controlled since the mold protrusion 87 extends completely over the upper surface and slightly beyond. Those of skill in the art will appreciate that in other embodiments, the mold protrusion 87 could also be made or configured to have the bleed-through retention channel 90 extend on two, three or all four sides.

The finished IC package 80 is shown in FIG. 10 wherein an upper surface 92 of the IC 81 is exposed through the opening 93 in the encapsulating material 91. In this illustrated embodiment, the substrate 84 extends outwardly beyond the side edges of the IC 81. In other embodiments, the side edges of the substrate 84 may be terminated flush with the side edges of the IC 81 as will be appreciated by those skilled in the art. The vestigial portions 95 of encapsulating material 91 are also schematically illustrated by the dashed line on the right hand side of the upper surface 92 of the IC 81.

It is further noted that although the encapsulating material 91 surrounds the IC 81, there is no encapsulating material 91 on the back surface of the IC in the illustrated IC package 80. In this embodiment, the substrate 84 provides the protection for the back surface.

Other aspects of the invention are disclosed in U.S. Patent Application Ser. No. 09/931,587, entitled "METHODS AND APPARATUS FOR MAKING INTEGRATED CIRCUIT PACKAGE INCLUDING OPENING EXPOSING PORTION OF THE IC" file concurrently herewith. The entire contents of this application are incorporated herein by reference. In addition, many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Accordingly, it is understood that the invention is not to be limited to the illustrated embodiments disclosed, and that other modifications and embodiments are intended to be included within the spirit and scope of the appended claims.

That which is claimed is:

1. An integrated circuit package comprising:
an integrated circuit (IC) and encapsulating material surrounding said IC,
said encapsulating material having an opening therein to define an exposed portion of said IC; and
vestigial portions of said encapsulating material on the exposed portion of said IC spaced inwardly from a periphery of the opening in said encapsulating material.
2. An integrated circuit package according to claim 1 wherein the opening in said encapsulating material is generally rectangular; and wherein said vestigial portions of encapsulating material are arranged along at least one side of an imaginary rectangle spaced inwardly from the generally rectangular opening in said encapsulating material.
3. An integrated circuit package according to claim 1 wherein said vestigial portions are spaced inwardly a distance of from 0.1 to 3 mm.
4. An integrated circuit package according to claim 1 further comprising a leadframe carrying said IC.
5. An integrated circuit package according to claim 4 wherein said leadframe comprises a die pad, finger portions, and a plurality of die pad support bars extending between said die pad and said finger portions.
6. An integrated circuit package according to claim 5 wherein said die pad is downset below a level of said finger portions.
7. An integrated circuit package according to claim 6 wherein each of said die pad support bars is resiliently deformed to accommodate the downset of said die pad.
8. An integrated circuit package according to claim 6 further comprising bond wires extending between said IC and the finger portion having a desired clearance from adjacent portions of said IC and an upper surface of said encapsulating material.
9. An integrated circuit package according to claim 5 wherein said die pad has an opening therein.
10. An integrated circuit package according to claim 5 further comprising a low stress, low modulus adhesive securing said IC to said die pad.
11. An integrated circuit package according to claim 1 further comprising a substrate adjacent a back surface of said IC opposite the exposed portion.
12. An integrated circuit package according to claim 1 wherein said substrate covers the back surface of said IC so that said encapsulating material does not extend onto the back surface.
13. An integrated circuit package according to claim 1 wherein said encapsulating material comprises a low stress encapsulating material.
14. An integrated circuit package according to claim 1 wherein said IC comprises upper surface portions with active devices formed therein; and wherein the exposed portion of said IC comprises upper surface portions thereof.
15. An integrated circuit package according to claim 14 wherein the active devices define a sensor.
16. An integrated circuit package according to claim 14 wherein the active devices define an electric field fingerprint sensor.
17. An integrated circuit package comprising:
an integrated circuit (IC) comprising upper surface portions with active devices formed therein and encapsulating material surrounding said IC;
said encapsulating material having an opening therein adjacent the upper surface portions of said IC to define an exposed portion of said IC; and
a leadframe comprising a die pad carrying said IC, finger portions, and a plurality of die pad support bars extending between said die pad and said finger portions;
said die pad being downset below a level of said finger portions.
18. An integrated circuit package according to claim 17 wherein each of said die pad support bars is resiliently deformed to accommodate the downset of said die pad.
19. An integrated circuit package according to claim 18 further comprising bond wires extending between said IC and the finger portion having a desired clearance from adjacent portions of said IC and an upper surface of said encapsulating material.
20. An integrated circuit package according to claim 17 wherein said die pad has an opening therein.
21. An integrated circuit package according to claim 20 further comprising a low stress, low modulus adhesive securing said IC to said die pad.
22. An integrated circuit package according to claim 17 wherein said encapsulating material comprises a low stress encapsulating material.
23. An integrated circuit package according to claim 17 further comprising vestigial portions of encapsulating material on the exposed portion of said IC and spaced inwardly from a periphery of the opening in said encapsulating material.
24. An integrated circuit package according to claim 23 wherein the opening in said encapsulating material is generally rectangular; and wherein said vestigial portions of encapsulating material are arranged along an imaginary rectangle spaced inwardly from the generally rectangular opening in said encapsulating material.
25. An integrated circuit package according to claim 23 wherein said vestigial portions are spaced inwardly a distance of from 0.1 to 3 mm.

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26. An integrated circuit package according to claim 17 wherein the active devices define a sensor.

27. An integrated circuit package according to claim 17 wherein the active devices define an electric field fingerprint sensor.

28. An integrated circuit package comprising:

an integrated circuit (IC) comprising upper surface portions with active devices formed therein and encapsulating material surrounding said IC;

said encapsulating material having an opening therein adjacent the upper surface portions of said IC to define an exposed portion of said IC; and

a leadframe comprising a die pad carrying said IC, finger portions, and a plurality of die pad support bars extending between said die pad and said finger portions, each of said die pad support bars being resiliently deformed.

29. An integrated circuit package according to claim 28 wherein said die pad is downset below a level of said finger portions.

30. An integrated circuit package according to claim 29 further comprising bond wires extending between said IC and the finger portion having a desired clearance from adjacent portions of said IC and an upper surface of said encapsulating material.

31. An integrated circuit package according to claim 28 wherein said die pad has an opening therein.

32. An integrated circuit package according to claim 31 further comprising a low stress, low modulus adhesive securing said IC to said die pad.

33. An integrated circuit package according to claim 28 wherein said encapsulating material comprises a low stress encapsulating material.

34. An integrated circuit package according to claim 28 further comprising vestigial portions of encapsulating material on the exposed portion of said IC and spaced inwardly from a periphery of the opening in said encapsulating material.³⁵

35. An integrated circuit package according to claim 34 wherein the opening in said encapsulating material is generally rectangular; and wherein said vestigial portions of encapsulating material are arranged along an imaginary rectangle spaced inwardly from the generally rectangular opening in said encapsulating material.

36. An integrated circuit package according to claim 34 wherein said vestigial portions are spaced inwardly a distance of from 0.1 to 3 mm.

37. An integrated circuit package according to claim 28 wherein the active devices define a sensor.

38. An integrated circuit package according to claim 28 wherein the active devices define an electric field fingerprint sensor.

39. An integrated circuit package comprising:

an integrated circuit (IC) comprising upper surface portions with active devices formed therein and encapsulating material surrounding said IC;

said encapsulating material having an opening therein adjacent the upper surface portions of said IC to define an exposed portion of said IC; and

a die pad carrying said IC, said die pad having an opening therein.

40. An integrated circuit package according to claim 39 further comprising finger portions, and a plurality of die pad support bars extending between said die pad and said finger portions, and wherein said die pad is downset below a level of said finger portions.

41. An integrated circuit package according to claim 40 wherein each of said die pad support bars is resiliently deformed to accommodate the downset of said die pad.⁶⁵

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42. An integrated circuit package according to claim 40 further comprising bond wires extending between said IC and the finger portion having a desired clearance from adjacent portions of said IC and an upper surface of said encapsulating material.

43. An integrated circuit package according to claim 39 further comprising a low stress, low modulus adhesive securing said IC to said die pad.

44. An integrated circuit package according to claim 39 wherein said encapsulating material comprises a low stress encapsulating material.

45. An integrated circuit package according to claim 39 further comprising vestigial portions of encapsulating material on the exposed portion of said IC and spaced inwardly from a periphery of the opening in said encapsulating material.¹⁵

46. An integrated circuit package according to claim 45 wherein the opening in said encapsulating material is generally rectangular; and wherein said vestigial portions of encapsulating material are arranged along an imaginary rectangle spaced inwardly from the generally rectangular opening in said encapsulating material.

47. An integrated circuit package according to claim 45 wherein said vestigial portions are spaced inwardly a distance of from 0.1 to 3 mm.²⁵

48. An integrated circuit package according to claim 39 wherein the active devices define a sensor.

49. An integrated circuit package according to claim 39 wherein the active devices define an electric field fingerprint sensor.³⁰

50. An integrated circuit package comprising:
an integrated circuit (IC) and encapsulating material surrounding said IC;
said encapsulating material having an opening therein to define an exposed portion of said IC; and
a substrate covering a back surface of said IC opposite the exposed portion so that said encapsulating material does not extend onto the back surface of said IC.³⁵

51. An integrated circuit package according to claim 50 wherein said substrate comprises a printed circuit board.

52. An integrated circuit package according to claim 50 further comprising vestigial portions of encapsulating material on the exposed portion of said IC and spaced inwardly from a periphery of the opening in said encapsulating material.⁴⁵

53. An integrated circuit package according to claim 52 wherein the opening in said encapsulating material is generally rectangular; and wherein said vestigial portions of encapsulating material are arranged along at least one side of an imaginary rectangle spaced inwardly from the generally rectangular opening in said encapsulating material.⁵⁰

54. An integrated circuit package according to claim 52 wherein said vestigial portions are spaced inwardly a distance of from 0.1 to 3 mm.⁵⁵

55. An integrated circuit package according to claim 52 wherein said encapsulating material comprises a low stress encapsulating material.

56. An integrated circuit package according to claim 52 wherein said IC comprises upper surface portions with active devices formed therein; and wherein the exposed portion of said IC comprises upper surface portions thereof.⁶⁰

57. An integrated circuit package according to claim 56 wherein the active devices define a sensor.

58. An integrated circuit package according to claim 57 wherein the active devices define an electric field fingerprint sensor.⁶⁵

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,667,439 B2
APPLICATION NO. : 09/931378
DATED : December 23, 2003
INVENTOR(S) : Salatino et al.

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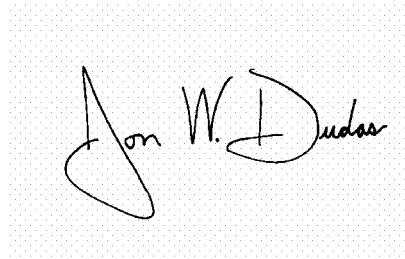
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 9, Line 46 Delete: "an spaced"
 Insert: -- and spaced --

Column 9, Line 47 Delete: "maid"
 Insert: -- said --

Signed and Sealed this

Thirtieth Day of January, 2007

A handwritten signature in black ink, appearing to read "Jon W. Dudas". The signature is written over a dotted rectangular background.

JON W. DUDAS
Director of the United States Patent and Trademark Office

EXHIBIT C



US005940526A

United States Patent [19]**Setlak et al.****Patent Number: 5,940,526****[45] Date of Patent: Aug. 17, 1999****[54] ELECTRIC FIELD FINGERPRINT SENSOR HAVING ENHANCED FEATURES AND RELATED METHODS**

[75] Inventors: **Dale R. Setlak; Nicolaas W. Van Vonna**, both of Melbourne; **Rex Lowther**, Palm Bay; **Dave Gebauer**, West Melbourne, all of Fla.

[73] Assignee: **Harris Corporation**, Palm Bay, Fla.

[21] Appl. No.: **08/858,144**

[22] Filed: **May 16, 1997**

[51] Int. Cl.⁶ **G06K 9/00**

[52] U.S. Cl. **382/124**

[58] Field of Search 382/124-127,
382/324; 348/294; 257/414, 428, 434, 446,
448, 758, 659, 355; 250/370.01, 370.08,
553; 340/825.34

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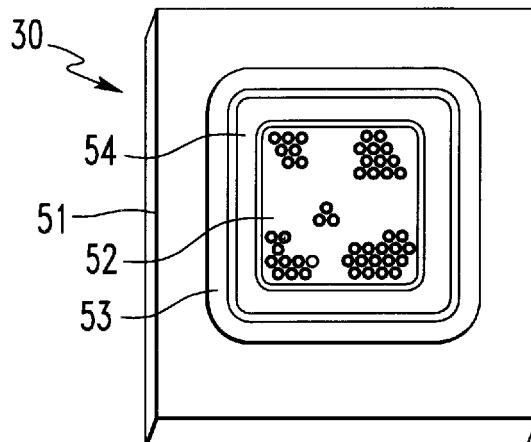
Primary Examiner—Leo H. Boudreau
Assistant Examiner—Dmitry A. Novik
Attorney, Agent, or Firm—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

[57]

ABSTRACT

A fingerprint sensor includes a plurality of semiconductor devices adjacent a substrate and defining active circuit portions, and having only three metal layers. More particularly, the sensor may include a first metal layer interconnecting predetermined ones of the plurality of semiconductor devices; a second metal layer defining a ground plane; and a third metal layer comprising an array of electric field sensing electrodes connected to active circuit portions for generating an output related to a sensed fingerprint. The fingerprint sensor may also include a package surrounding the substrate and having an opening aligned with the sensing electrodes. In addition, a first external electrode may be carried by the package for contact by a finger. The sensor may thus also include an excitation drive circuit connected between the ground plane and the first external electrode for generating electric fields between the electric field sensing electrodes and adjacent finger portions. A power control circuit is for controlling operation of active circuit portions based upon sensing finger contact with the first external electrode so that the active circuit portions are powered upon sensing finger contact with the first external electrode and otherwise grounded. A second external electrode may be connected to a bleed resistor to bleed charge from the finger prior to switching from the grounded to the powered state. An amplifier connected between each electric field sensing electrode and associated shield electrode may be operated at a gain of greater than one for additional noise rejection.

36 Claims, 6 Drawing Sheets



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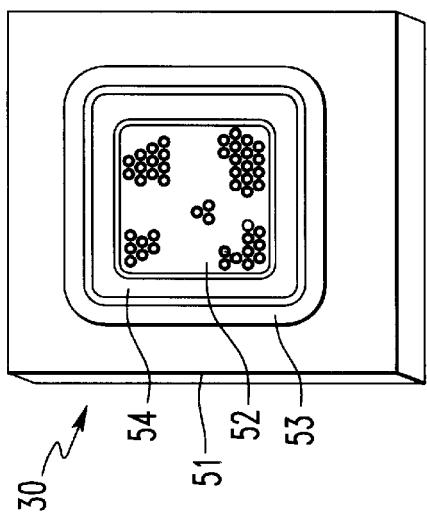


FIG. 1

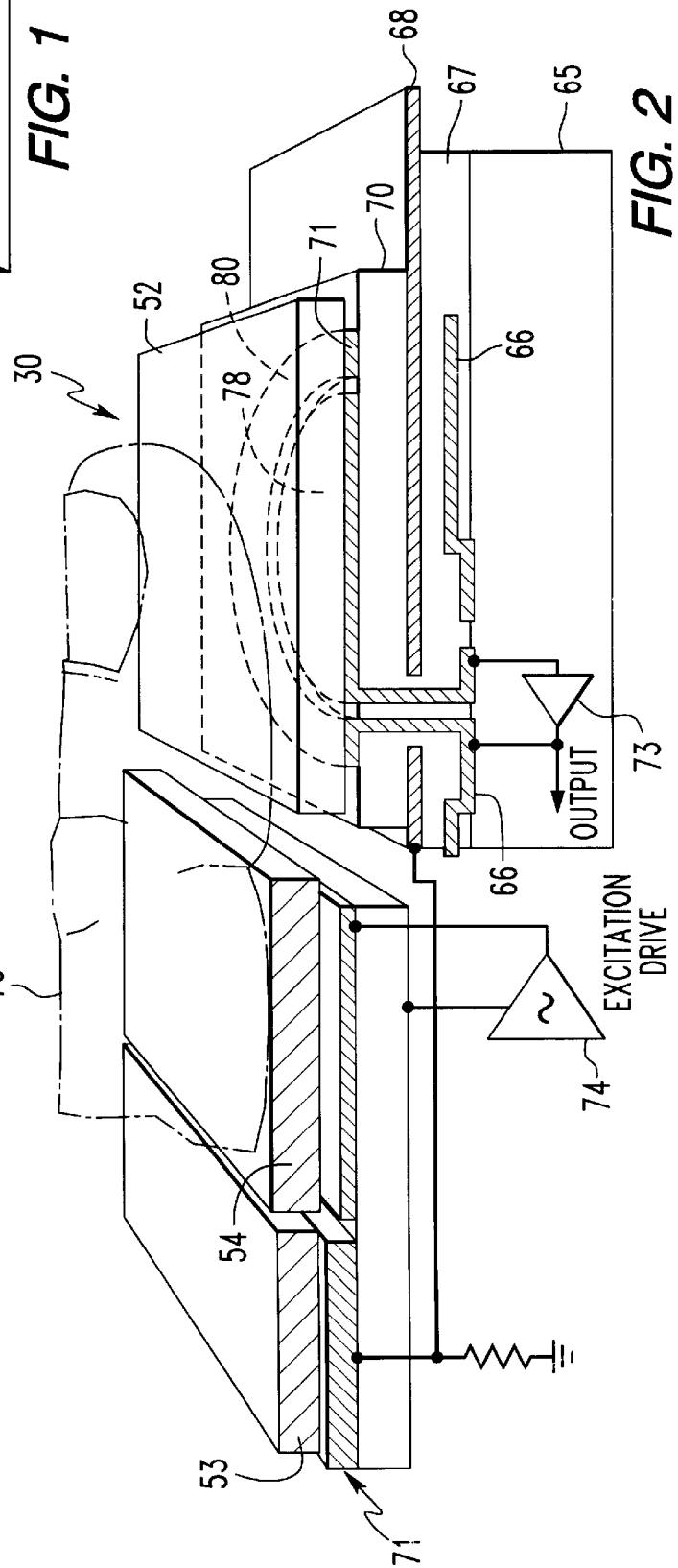
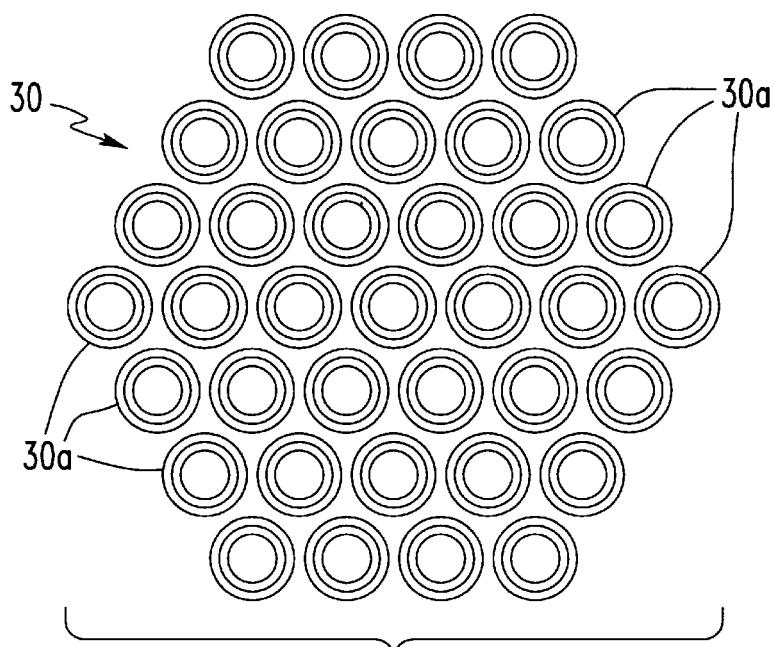
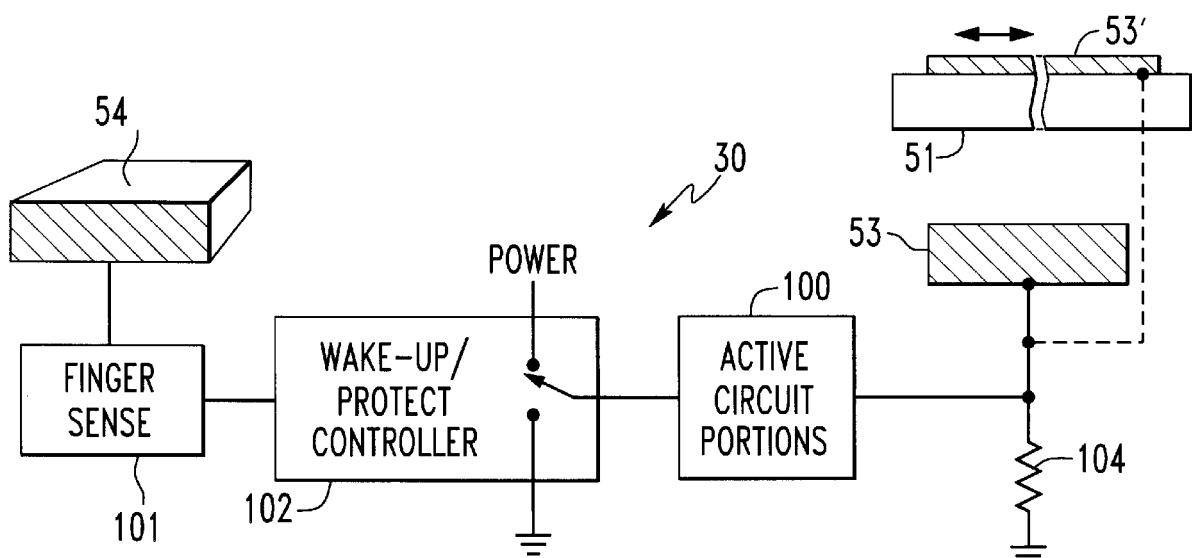


FIG. 2

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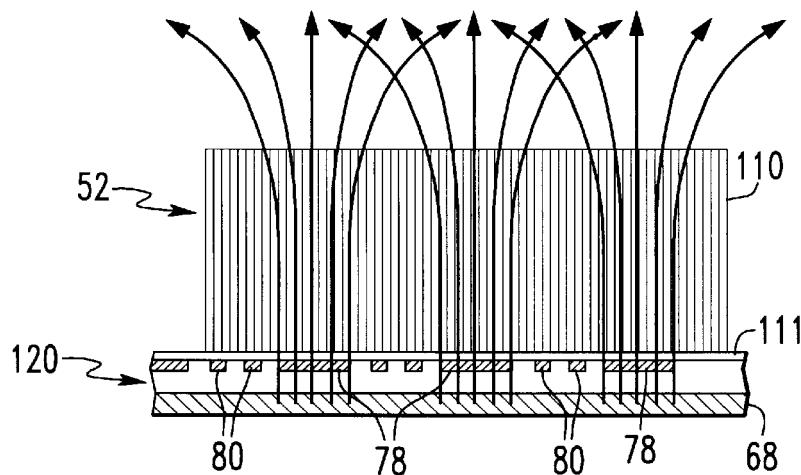
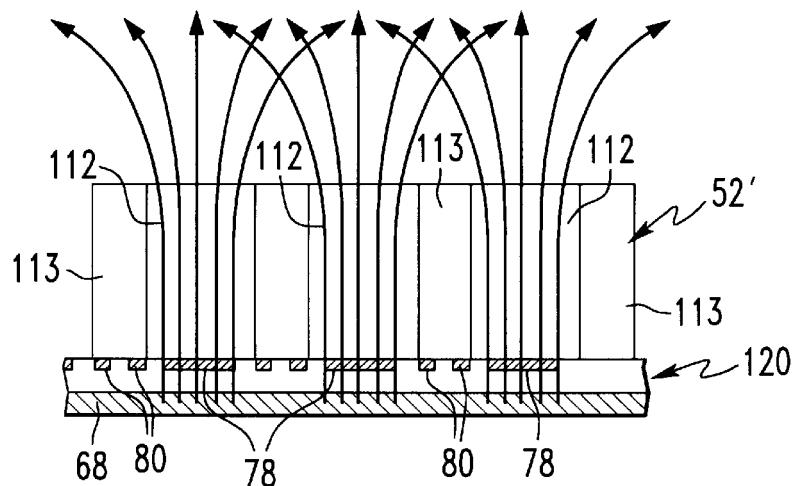
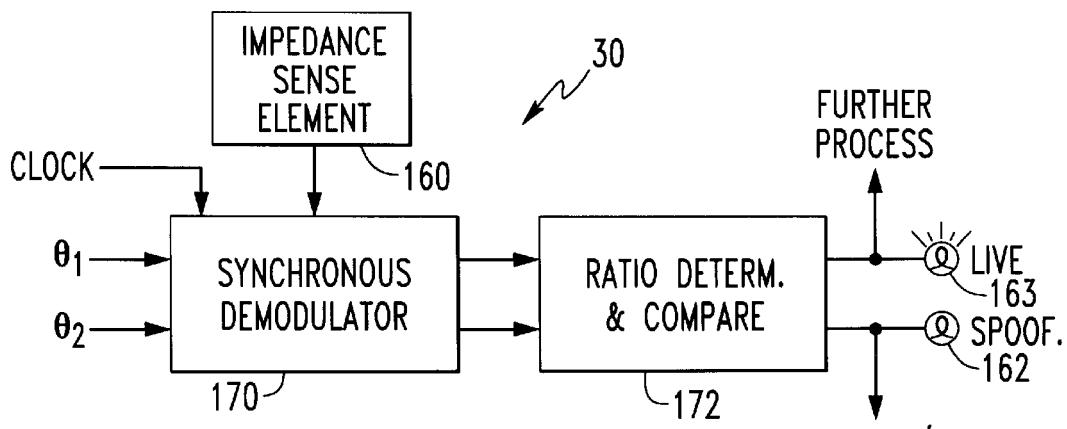
5,940,526**FIG. 3****FIG. 4**

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***FIG. 5******FIG. 6******FIG. 11***

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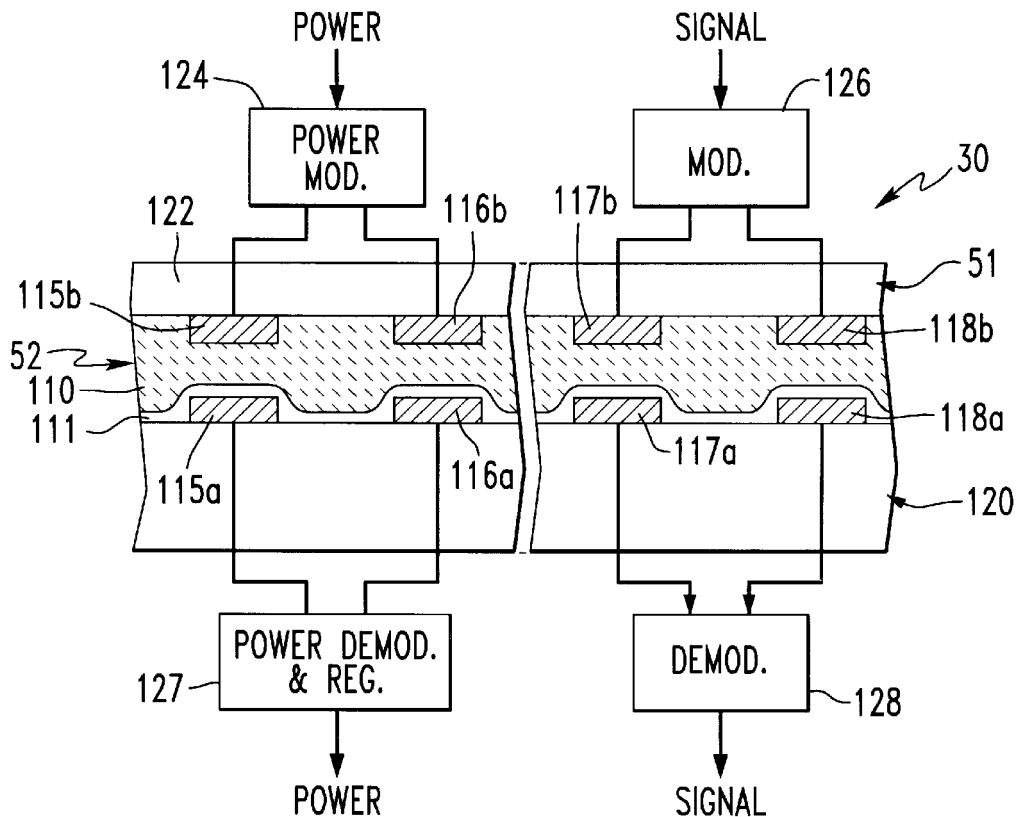


FIG. 7

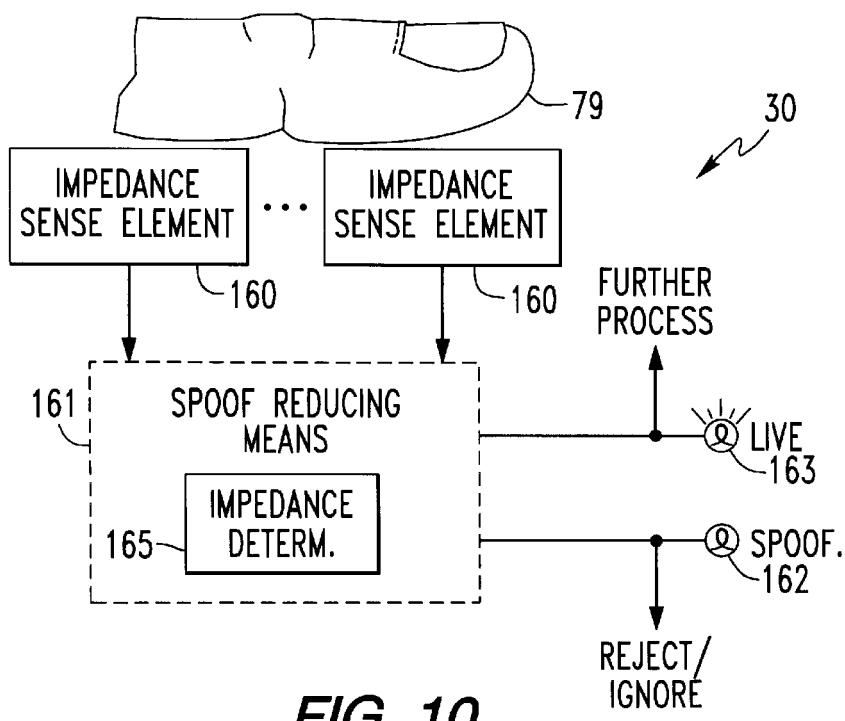


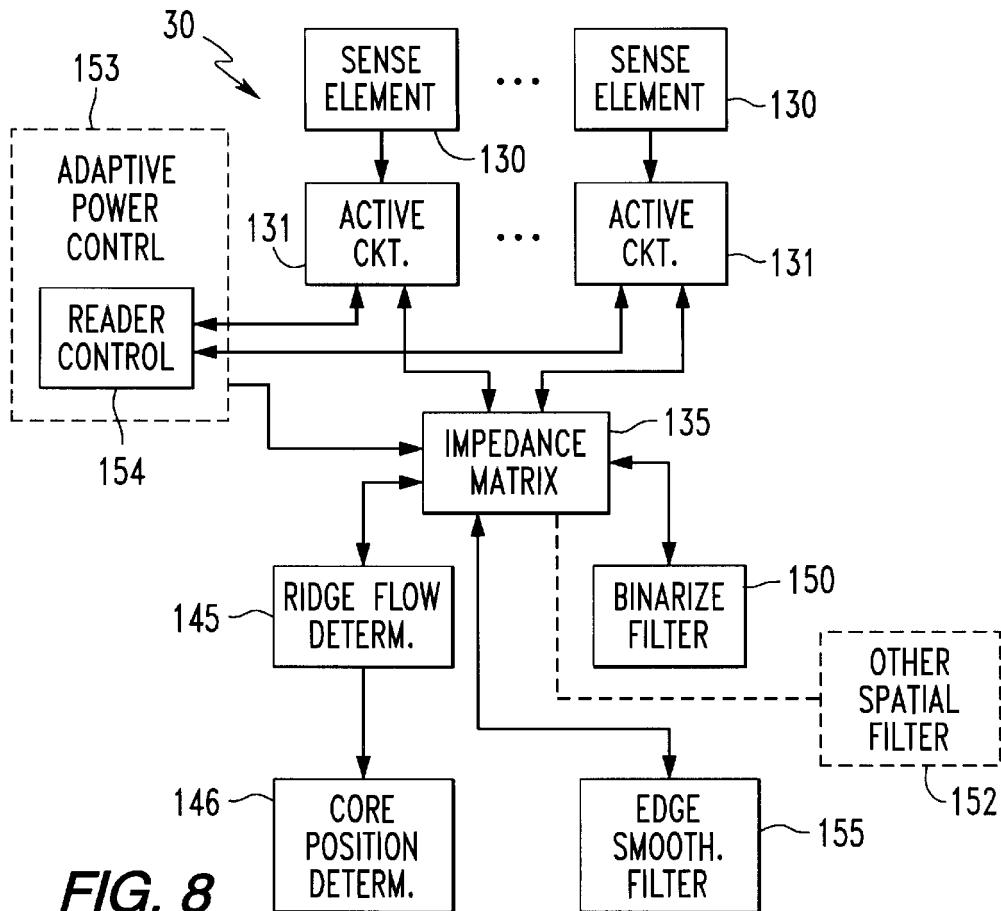
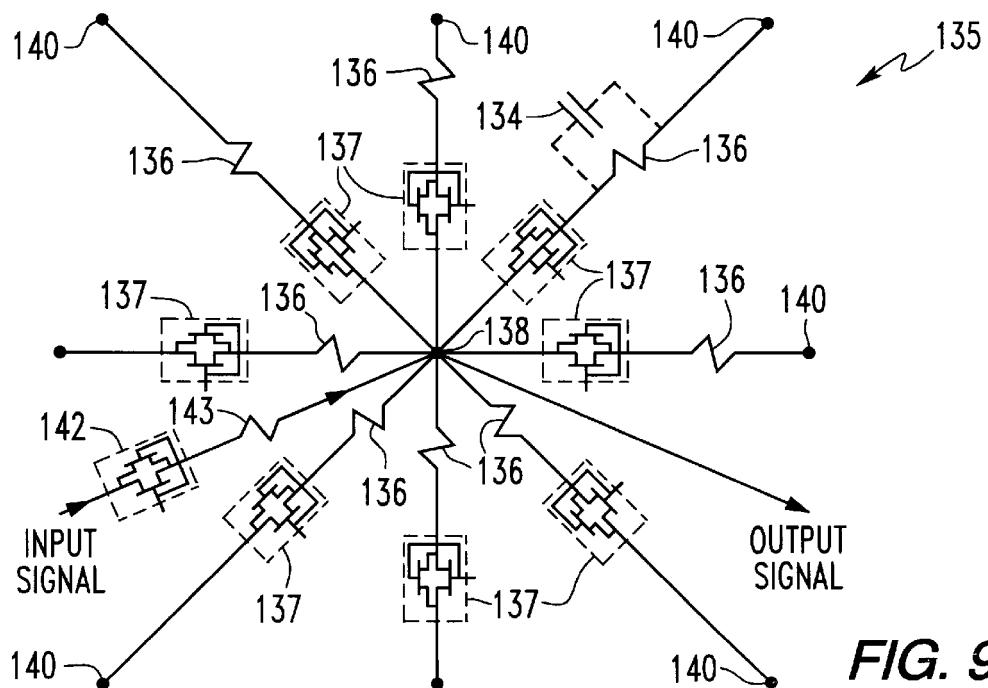
FIG. 10

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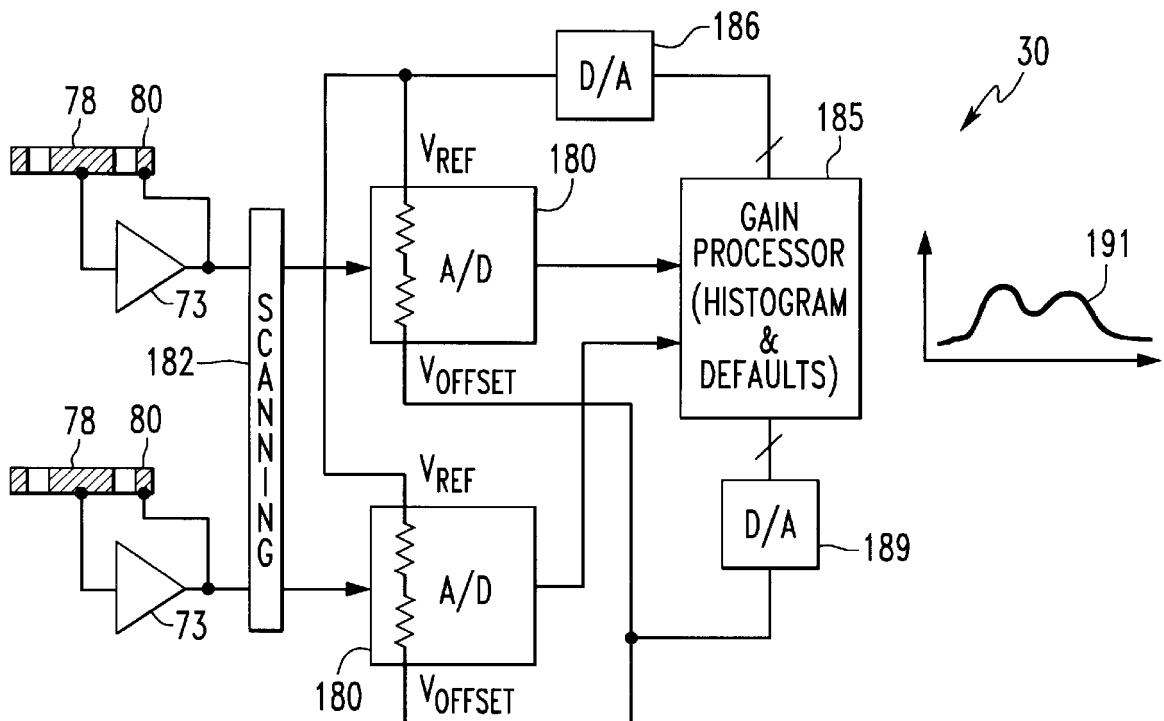
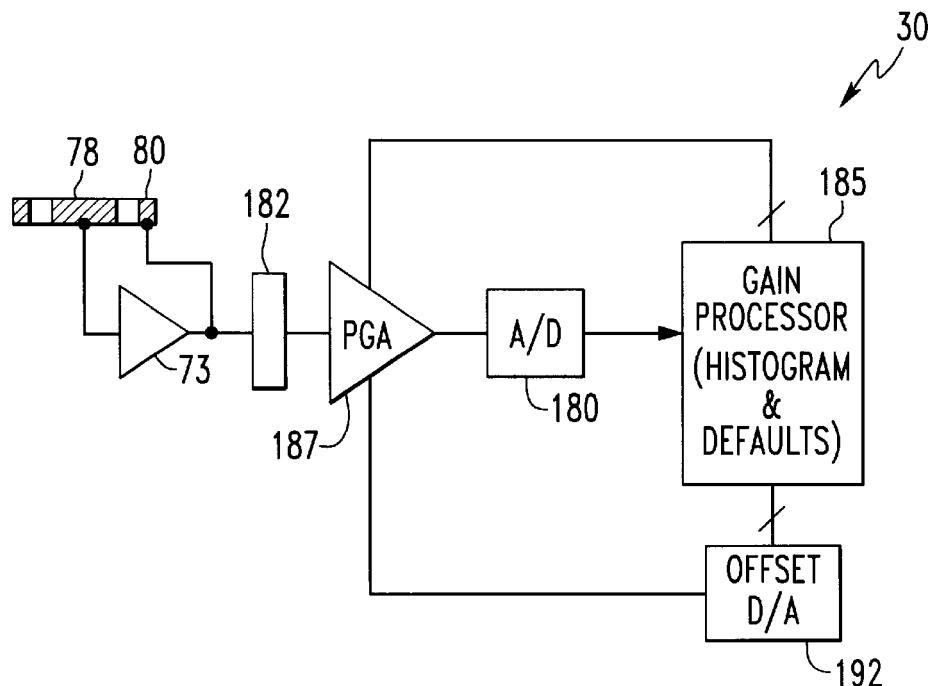
**FIG. 8****FIG. 9**

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***FIG. 12******FIG. 13***

**ELECTRIC FIELD FINGERPRINT SENSOR
HAVING ENHANCED FEATURES AND
RELATED METHODS**

FIELD OF THE INVENTION

The present invention relates to the field of personal identification and verification, and, more particularly, to the field of fingerprint sensing and processing.

BACKGROUND OF THE INVENTION

Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. In particular, a common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in a database to determine proper identification of a person, such as for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. For example, U.S. Pat. No. 4,210,899 to Swonger et al. discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. U.S. Pat. No. 4,525,859 to Bowles similarly discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. In addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams. Accordingly, optical sensors may thus be bulky and be susceptible to shock, vibration and surface contamination. Accordingly, an optical fingerprint sensor may be unreliable in service in addition to being bulky and relatively expensive due to optics and moving parts.

U.S. Pat. No. 4,353,056 to Tsikos discloses another approach to sensing a live fingerprint. In particular, the patent discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques. Unfortunately, the resilient materials required for the sensor may suffer from long term reliability problems. In addition, multiplexing techniques for driving and scanning each of the individual capacitors may be relatively slow and cumbersome. Moreover, noise and stray capacitances may adversely affect the plurality of relatively small and closely spaced capacitors.

U.S. Pat. No. 5,325,442 to Knapp discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing

electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying portion of the finger surface which, in turn, is at ground potential. The sensor may be fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes. Further conductors may be provided on the surface of the dielectric material remote from the sensing electrodes and extending over regions between the sensing electrodes, for example, as lines or in grid form, which conductors are grounded in order to improve the electrical contact to the finger surface.

Unfortunately, driving the array of closely spaced sensing electrodes as disclosed in the Knapp et al. patent may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. Yet another difficulty with such a sensor, as with many optical sensors, is that different portions of the fingerprint may require relatively complicated post image collection processing to provide for usable signal levels and contrast to thereby permit accurate determination of the ridges and valleys of the fingerprint. For example, U.S. Pat. No. 4,811,414 to Fishbine et al. discloses methods for noise averaging, illumination equalizing, directional filtering, curvature correcting, and scale correcting for an optically generated fingerprint image. Unfortunately, the various processing steps are complex and require considerable computational power in a downstream processor. Signal processing of other fingerprint circuits may also be relatively complicated and therefore expensive and/or slow.

Greater advances in fingerprint sensing and matching for identification and verification are desirable for many applications. Unfortunately, current sensors and their associated circuitry may be too bulky, expensive and unreliable for a great many applications which would otherwise benefit from fingerprint identification and verification technology. Conventional sensors typically consume relatively large amounts of power and may also be susceptible to damage from electrostatic discharges (ESD).

SUMMARY OF THE INVENTION

In view of the foregoing background, it is therefore an object of the present invention to provide a fingerprint sensor and associated methods which is relatively inexpensive, robust, and which is energy efficient.

This and other objects, advantages, and features of the present invention are provided by one embodiment of a fingerprint sensor including a plurality of semiconductor devices adjacent a substrate and defining active circuit portions, and having only three metal layers. More particularly, the sensor may include a first metal layer interconnecting predetermined ones of the plurality of semiconductor devices; a second metal layer adjacent the first dielectric layer defining a ground plane; and a third metal layer comprising an array of electric field sensing electrodes connected to active circuit portions for generating signals related to a sensed fingerprint. Intervening first and second dielectric layers may be positioned between the first and second, and second and third metal layers, respectively. A third dielectric layer may also be provided adjacent the third metal layer.

The fingerprint sensor may also include a package surrounding the substrate and having an opening aligned with

the array of electric field sensing electrodes. In addition, a first external electrode may be carried by the package for contact by a finger. The sensor may thus also include excitation drive means connected between the ground plane and the first external electrode for generating electric fields between the electric field sensing electrodes and adjacent finger portions.

One important aspect of the invention is the provision of power control means for controlling operation of active circuit portions based upon sensing finger contact with the first external electrode. The power control means may include wake-up means for only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power. Alternately or additionally, the power control means may further comprise protection means for grounding active circuit portions upon not sensing finger contact with the first external electrode.

Moreover, the fingerprint sensor may further comprise finger charge bleed means for bleeding a charge from a finger upon contact therewith. The finger charge bleed means may be provided by a second external electrode carried by the package for contact by a finger, and a charge bleed resistor connected between the second external electrode and an earth ground. In addition, the finger charge bleed means and power control means may be such that the active portions remain grounded until the charge bleed means can remove the charge on the finger before powering the active circuit portions. Accordingly, power may be conserved in the sensor and ESD protection provided by the sensor so that the sensor is relatively inexpensive, yet robust and conserves power.

To provide additional noise rejection, the sensor may include pairs of electric field sensing electrodes and associated shield electrodes. In addition, an amplifier may be connected between each pair. Moreover, each amplifier may be operated at an amplification gain of greater than about one to thereby provide additional noise rejection.

A method aspect of the invention is for making a fingerprint sensor. The method preferably comprises the steps of: forming a plurality of semiconductor devices adjacent a substrate and defining active circuit portions; forming a first metal layer interconnecting predetermined ones of the plurality of semiconductor devices; forming a first dielectric layer adjacent the first metal layer; forming a second metal layer adjacent the first dielectric layer defining a ground plane; forming a second dielectric layer adjacent the second metal layer; and forming a third metal layer adjacent the second dielectric layer and comprising an array of electric field sensing electrodes connected to active circuit portions for generating signals related to a sensed fingerprint.

Another method aspect of the invention is for controlling operation of a fingerprint sensor of a type comprising a plurality of semiconductor devices adjacent a substrate and defining active circuit portions for generating an output related to a sensed fingerprint, a package surrounding the substrate, and a first external electrode carried by the package for contact by a finger. This method preferably comprises the steps of: only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power, and grounding active circuit portions upon not sensing finger contact with the first external electrode. The method may further include the step of bleeding a charge from the finger upon initial contact of the finger with the fingerprint package and before switching from grounding of the active circuit portions to powering same.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top plan view of a fingerprint sensor in accordance with the present invention.

FIG. 2 is a schematic view of a circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 3 is a greatly enlarged top plan view of the sensing portion of the fingerprint sensor as shown in FIG. 1.

FIG. 4 is a schematic diagram of another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 5 is a greatly enlarged side cross-sectional view of a portion of the fingerprint sensor as shown in FIG. 1.

FIG. 6 is a greatly enlarged side cross-sectional view of a portion of an alternate embodiment of the fingerprint sensor in accordance with the invention.

FIG. 7 is a greatly enlarged side cross-sectional view of another portion of the fingerprint sensor as shown in FIG. 1.

FIG. 8 is a schematic block diagram of yet another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 9 is a schematic circuit diagram of a portion of the circuit as shown in FIG. 8.

FIG. 10 is a schematic block diagram of still another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 11 is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. 10.

FIG. 12 is a schematic block diagram of an additional circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 13 is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. 12.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. The scaling of various features, particularly layers in the drawing figures, have been exaggerated for clarity of explanation.

Referring to FIGS. 1-3, the fingerprint sensor 30 in accordance with the invention is initially described. The illustrated sensor 30 includes a housing or package 51, a dielectric layer 52 exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of output pins, not shown. A first conductive strip or external electrode 54 around the periphery of the dielectric layer 52, and a second external electrode 53 provide contact electrodes for the finger 79 as described in greater detail below. The sensor 30 may provide output signals in a range of sophistication levels depending on the level of processing incorporated in the package as would be readily understood by those skilled in the art.

The sensor 30 includes a plurality of individual pixels or sensing elements 30a arranged in array pattern as perhaps best shown in FIG. 3. As would be readily understood by those skilled in the art, these sensing elements are relatively small so as to be capable of sensing the ridges 59 and intervening valleys 60 of a typical fingerprint. As will also be readily appreciated by those skilled in the art, live fingerprint readings as from the electric field sensor 30 in

accordance with the present invention may be more reliable than optical sensing, because the impedance of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate. In contrast, an optical sensor may be deceived by a readily deceived by a photograph or other similar image of a fingerprint, for example.

The sensor 30 includes a substrate 65, and one or more active semiconductor devices formed thereon, such as the schematically illustrated amplifier 73. A first metal layer 66 interconnects the active semiconductor devices. A second or ground plane electrode layer 68 is above the first metal layer 66 and separated therefrom by an insulating layer 67. A third metal layer 71 is positioned over another dielectric layer 70. In the illustrated embodiment, the first external electrode 54 is connected to an excitation drive amplifier 74 which, in turn, drives the finger 79 with a signal may be typically in the range of about 1 KHz to 1 MHz. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor 30 may be relatively low, while the reliability is great.

An illustratively circularly shaped electric field sensing electrode 78 is on the insulating layer 70. The sensing electrode 78 may be connected to sensing integrated electronics, such as the illustrated amplifier 73 formed adjacent the substrate 65 as schematically illustrated, and as would be readily appreciated by those skilled in the art.

An annularly shaped shield electrode 80 surrounds the sensing electrode 78 in spaced relation therefrom. As would be readily appreciated by those skilled in the art, the sensing electrode 78 and its surrounding shield electrode 80 may have other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements 30a. The shield electrode 80 is an active shield which is driven by a portion of the output of the amplifier 73 to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electric field sensing electrodes 78.

The sensor 30 includes only three metal or electrically conductive layers 66, 68 and 71. The sensor 30 can be made without requiring additional metal layers which would otherwise increase the manufacturing cost, and, perhaps, reduce yields. Accordingly, the sensor 30 is less expensive and may be more rugged and reliable than a sensor including four or more metal layers as would be appreciated by those skilled in the art.

Another important aspect of the present invention is that the amplifier 73 may be operated at a gain of greater than about one to drive the shield electrode 80. Stability problems do not adversely affect the operation of the amplifier 73. Moreover, the common mode and general noise rejection are greatly enhanced according to this feature of the invention. In addition, the gain greater than one tends to focus the electric field with respect to the sensing electrode 78 as will be readily appreciated by those skilled in the art.

In general, the sensing elements 30a operate at very low currents and at very high impedances. For example, the output signal from each sensing electrode 78 is desirably about 5 to 10 millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element 30a, as defined by the outer dimensions of the shield electrode 80, may be about 0.002 to 0.005 inches in diameter. The ground plane electrode 68 protects the active electronic devices from unwanted excitation. The various signal feedthrough conductors for the electrodes 78, 80 to the active electronic circuitry may be readily formed as would be understood by those skilled in the art.

The overall contact or sensing surface for the sensor 30 may desirably be about 0.5 by 0.5 inches — a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor 30 in accordance with the invention is also fairly tolerant of dead pixels or sensing elements 30a. A typical sensor 30 includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor 30 may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

Turning now additionally to FIG. 4, another aspect of the sensor 30 of the invention is described. The sensor may include power control means for controlling operation of active circuit portions 100 based upon sensing finger contact with the first external electrode 54 as determined by the illustrated finger sense block or circuit 101. For example, the finger sense circuit 101 may operate based upon a change in impedance to an oscillator to thereby determine finger contact. Of course, other approaches for sensing contact with the finger are also contemplated by the invention. The power control means may include wake-up means for only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power. Alternately or additionally, the power control means may further comprise protection means for grounding active circuit portions upon not sensing finger contact with the first external electrode. In the illustrated embodiment, a combination of wake-up and protection controller circuits 102 are illustrated.

Moreover, the fingerprint sensor 30 may further comprise finger charge bleed means for bleeding a charge from a finger or other object upon contact therewith. The finger charge bleed means may be provided by the second external electrode 53 carried by the package 51 for contact by a finger, and a charge bleed resistor 104 connected between the second external electrode and an earth ground. As schematically illustrated in the upper right hand portion of FIG. 4, the second electrode may alternately be provided by a movable electrically conductive cover 53' slidably connected to the package 51 for covering the opening to the exposed upper dielectric layer 52. A pivotally connected cover is also contemplated by the present invention. Accordingly, under normal conditions, the charge would be bled from the finger as the cover 53' is moved to expose the sensing portion of the sensor 30.

In addition, the finger charge bleed means and power control means may be such that the active portions remain grounded until the charge bleed means can remove the charge on the finger before powering the active circuit portions, such as by providing a brief delay during wake-up sufficient to permit the charge to be discharged through the resistor 104 as would be readily understood by those skilled in the art. Accordingly, power may be conserved in the sensor 30 and ESD protection provided by the sensor so that the sensor is relatively inexpensive, yet robust and conserves power.

Referring now additionally to FIG. 5 yet another significant feature of the sensor 30 is described. The dielectric covering 52 may preferably comprise a z-axis anisotropic dielectric layer 110 for focussing an electric field, shown by the illustrated field lines, at each of the electric field sensing electrodes 78. In other words, the dielectric layer 110 may be relatively thick, but not result in defocussing of the electric fields propagating therethrough because of the z-axis anisotropy of the material. Typically there would be a trade-off

between field focus and mechanical protection. Unfortunately, a thin film which is desirable for focussing, may permit the underlying circuit to be more easily subject to damage.

The z-axis anisotropic dielectric layer 110 of the present invention, for example, may have a thickness in range of about 0.0001 to 0.004 inches. Of course, the z-axis anisotropic dielectric layer 110 is also preferably chemically resistant and mechanically strong to withstand contact with fingers, and to permit periodic cleanings with solvents. The z-axis anisotropic dielectric layer 110 may preferably define an outermost protective surface for the integrated circuit die 120. Accordingly, the overall dielectric covering 52 may further include at least one relatively thin oxide, nitride, carbide, or diamond layer 111 on the integrated circuit die 120 and beneath the z-axis anisotropic dielectric layer 110. The thin layer 111 will typically be relatively hard, and the z-axis anisotropic dielectric layer 110 is desirably softer to thereby absorb more mechanical activity.

The z-axis anisotropic dielectric layer 110 may be provided by a plurality of oriented dielectric particles in a cured matrix. For example, the z-axis anisotropic dielectric layer 110 may comprise barium titanate in a polyimide matrix. Those of skill in the art will appreciate other materials exhibiting z-axis anisotropy suitable for the present invention. For example, certain ceramics exhibit dielectric anisotropy as would also be appreciated by those skilled in the art.

Turning to FIG. 6, another variation of a z-axis dielectric covering 52' is schematically shown by a plurality of high dielectric portions 112 aligned with corresponding electric field sensing electrodes 78, and a surrounding matrix of lower dielectric portions 113. This embodiment of the dielectric covering 52' may be formed in a number of ways, such as by forming a layer of either the high dielectric or low dielectric portions, selectively etching same, and filling the openings with the opposite material. Another approach may be to use polarizable microcapsules and subjecting same to an electric field during curing of a matrix material. A material may be compressed to cause the z-axis anisotropy. Laser and other selective processing techniques may also be used as would be readily understood by those skilled in the art.

Another aspect of the invention relates to being able to completely cover and protect the entire upper surface of the integrated circuit die 120, and still permit connection and communication with the external devices and circuits as now further explained with reference to FIG. 7. The third metal layer 71 (FIG. 2) preferably further includes a plurality of capacitive coupling pads 116a-118a for permitting capacitive coupling of the integrated circuit die 120. Accordingly, the dielectric covering 52 is preferably continuous over the capacitive coupling pads 116a-118a and the array of electric field sensing electrodes 78 of the pixels 30a (FIG. 1). In sharp contrast to this feature of the present invention, it is conventional to create openings through an outer coating to electrically connect to the bond pads. Unfortunately, these openings would provide pathways for water and/or other contaminants to come in contact with and damage the die.

A portion of the package 51 includes a printed circuit board 122 which carries corresponding pads 115b-118b. A power modulation circuit 124 is coupled to pads 115b-116b, while a signal modulation circuit 126 is illustrative coupled to pads 117b-118b. As would be readily understood by those skilled in the art, both power and signals may be readily coupled between the printed circuit board 122 and the integrated circuit die 120, further using the illustrated power

demodulation/regulator circuit 127, and the signal demodulation circuit 128. The z-axis anisotropic dielectric layer 110 also advantageously reduces cross-talk between adjacent capacitive coupling pads. This embodiment of the invention 30 presents no penetrations through the dielectric covering 52 for moisture to enter and damage the integrated circuit die 120. In addition, another level of insulation is provided between the integrated circuit and the external environment.

For the illustrated fingerprint sensor 30, the package 51 preferably has an opening aligned with the array of electric field sensing electrodes 78 (FIGS. 1-3). The capacitive coupling and z-axis anisotropic layer 110 may be advantageously used in a number of applications in addition to the illustrated fingerprint sensor 30, and particularly where it is desired to have a continuous film covering the upper surface of the integrated circuit die 120 and pads 116a-118a.

Further aspects of the manufacturing of the sensor 30 including the z-axis anisotropic dielectric material are explained in U.S. patent application Ser. No. 08/857,525 filed May 16, 1997, entitled "Direct Chip Attachment Method and Devices Produced Thereby". This patent application has attorney work docket no. 18763, is assigned to the present assignee, and the entire disclosure of which is incorporated herein by reference.

Referring additionally to FIGS. 8 and 9, impedance matrix filtering aspects of the invention are now described. As shown in FIG. 8, the fingerprint sensor 30 may be considered as comprising an array of fingerprint sensing elements 130 and associated active circuits 131 for generating signals relating to the fingerprint image. The illustrated sensor 30 also includes an impedance matrix 135 connected to the active circuits for filtering the signals therefrom.

As shown with more particular reference to FIG. 9, the impedance matrix 135 includes a plurality of impedance elements 136 with a respective impedance element connectable between each active circuit of a respective fingerprint sensing element as indicated by the central node 138, and the other active circuits (outer nodes 140). The impedance matrix 135 also includes a plurality of switches 137 with a respective switch connected in series with each impedance element 136. An input signal may be supplied to the central node 138 via the illustrated switch 142 and its associated impedance element 143. The impedance element may one or more of a resistor as illustrated, and a capacitor 134 as would be readily appreciated by those skilled in the art.

Filter control means may operate the switches 137 to perform processing of the signals generated by the active circuits 131. In one embodiment, the fingerprint sensing elements 130 may be electric field sensing electrodes 78, and the active circuits 131 may be amplifiers 73 (FIG. 2). Of course other sensing elements and active circuits may also benefit from the impedance matrix filtering of the present invention as would be readily understood by those skilled in the art.

Ridge flow determining means 145 may be provided for selectively operating the switches 137 of the matrix 135 to determine ridge flow directions of the fingerprint image. More particularly, the ridge flow determining means 145 may selectively operate the switches 137 for determining signal strength vectors relating to ridge flow directions of the fingerprint image. As would be readily understood by those skilled in the art, the ridge flow directions may be determined based upon well known rotating slit principles.

The sensor 30 may include core location determining means 146 cooperating with the ridge flow determining means 145 for determining a core location of the fingerprint

image. The position of the core is helpful, for example, in extracting and processing minutiae from the fingerprint image as would also be readily understood by those skilled in the art.

As also schematically illustrated in FIG. 8, a binarizing filter 150 may be provided for selectively operating the switches 137 to convert a gray scale fingerprint image to a binarized fingerprint image. Considered another way, the impedance matrix 135 may be used to provide dynamic image contrast enhancement. In addition, an edge smoothing filter 155 may be readily implemented to improve the image. As also schematically illustrated other spatial filters 152 may also be implemented using the impedance matrix 135 for selectively operating the switches 137 to spatially filter the fingerprint image as would be readily appreciated by those of skill in the art. Accordingly, processing of the fingerprint image may be carried out at the sensor 30 and thereby reduce additional downstream computational requirements.

As shown in the illustrated embodiment of FIG. 9, the impedance matrix 135 may comprise a plurality of impedance elements with a respective impedance element 136 connectable between each active circuit for a given fingerprint sensing element 130 and eight other active circuits for respective adjacent fingerprint sensing elements.

Yet another aspect of the invention is the provision of control means 153 for sequentially powering sets of active circuits 131 to thereby conserve power. Of course, the respective impedance elements 136 are desirably also sequentially connected to perform the filtering function. The powered active circuits 131 may be considered as defining a cloud or kernel as would be readily appreciated by those skilled in the art. The power control means 153 may be operated in an adaptive fashion whereby the size of the area used for filtering is dynamically changed for preferred image characteristics as would also be readily understood by those skilled in the art. In addition, the power control means 153 may also power only certain ones of the active circuits corresponding to a predetermined area of the array of sensing elements 130. For example, every other active circuit 131 could be powered to thereby provide a larger area, but reduced power consumption as would also be understood by those skilled in the art.

Reader control means 154 may be provided to read only predetermined subsets of each set of active circuits 131 so that a contribution from adjacent active circuits is used for filtering. In other words, only a subset of active circuits 131 are typically simultaneously read although adjacent active circuits 131 and associated impedance elements 136 are also powered and connected, respectively. For example, 16 impedance elements 136 could define a subset and be readily simultaneously read. The subset size could be optimized for different sized features to be determined as would be readily appreciated by those skilled in the art.

Accordingly, the array of sense elements 130 can be quickly read, and power consumption substantially reduced since all of the active circuits 131 need not be powered for reading a given set of active circuits. For a typical sensor, the combination of the power control and impedance matrix features described herein may permit power savings by a factor of about 10 as compared to powering the full array.

It is another important advantage of the fingerprint sensor 30 according to present invention to guard against spoofing or deception of the sensor into incorrectly treating a simulated image as a live fingerprint image. For example, optical sensors may be deceived or spoofed by using a paper with a fingerprint image thereon. The unique electric field sensing

of the fingerprint sensor 30 of the present invention provides an effective approach to avoiding spoofing based upon the complex impedance of a finger.

As shown in FIG. 10, the fingerprint sensor 30 may be considered as including an array of impedance sensing elements 160 for generating signals related to a finger 79 or other object positioned adjacent thereto. In the embodiment described herein, the impedance sensing elements 160 are provided by electric field sensing electrodes 78 and amplifiers 73 (FIG. 2) associated therewith. In addition, a guard shield 80 may be associated with each electric field sensing electrode 78 and connected to a respective amplifier 73. Spoof reducing means 161 is provided for determining whether or not an impedance of the object positioned adjacent the array of impedance sensing elements 160 corresponds to a live finger 79 to thereby reduce spoofing of the fingerprint sensor by an object other than a live finger. A spoofing may be indicated, such as by the schematically illustrated lamp 163 and/or used to block further processing. Alternately, a live fingerprint determination may also be indicated by a lamp 164 and/or used to permit further processing of the fingerprint image as will be readily appreciated by those skilled in the art. Many other options for indicating a live fingerprint or an attempted spoofing will be readily appreciated by those skilled in the art.

In one embodiment, the spoof reducing means 161 may include impedance determining means 165 to detect a complex impedance having a phase angle in a range of about 10 to 60 degrees corresponding to a live finger 79. Alternately, the spoof reducing means 161 may detect an impedance having a phase angle of about 0 degrees corresponding to some objects other than a live finger, such as a sheet of paper having an image thereon, for example. In addition, the spoof reducing means 161 may detect an impedance of 90 degrees corresponding to other objects.

Turning now to FIG. 11, another embodiment of spoof reducing means is explained. The fingerprint sensor 30 may preferably includes drive means for driving the array of impedance sensing elements 160, such as the illustrated excitation amplifier 74 (FIG. 2). The sensor also includes synchronous demodulator means 170 for synchronously demodulating signals from the array of impedance sensing elements 160. Accordingly, in one particularly advantageous embodiment of the invention, the spoof reducing means comprises means for operating the synchronous demodulator means 170 at at least one predetermined phase rotation angle. For example, the synchronous demodulator means 170 could be operated in a range of about 10 to 60 degrees, and the magnitude compared to a predetermined threshold indicative of a live fingerprint. A live fingerprint typically has a complex impedance within the range of 10 to 60 degrees.

Alternately, ratio generating and comparing means 172 may be provided for cooperating with the synchronous demodulator means 170 for synchronously demodulating signals at first and second phase angles θ_1, θ_2 , generating an amplitude ratio thereof, and comparing the amplitude ratio to a predetermined threshold to determine whether the object is a live fingerprint or other object. Accordingly, the synchronous demodulator 170 may be readily used to generate the impedance information desired for reducing spoofing of the sensor 30 by an object other than a live finger. The first angle θ_1 and the second θ_2 may have a difference in a range of about 45 to 90 degrees, for example. Other angles are also contemplated by the invention as would be readily appreciated by those skilled in the art.

The fingerprint sensor 30 also includes an automatic gain control feature to account for a difference in intensity of the

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image signals generated by different fingers or under different conditions, and also to account for differences in sensor caused by process variations. It is important for accurately producing a fingerprint image, that the sensor can discriminate between the ridges and valleys of the fingerprint. Accordingly, the sensor **30** includes a gain control feature, a first embodiment of which is understood with reference to FIG. **12**.

As shown in FIG. **12**, the illustrated portion of the fingerprint sensor **30** includes an array of fingerprint sensing elements in the form of the electric field sensing electrodes **78** and surrounding shield electrodes **80** connected to the amplifiers **73**. Other fingerprint sensing elements may also benefit from the following automatic gain control implementations as will be appreciated by those skilled in the art.

The signal processing circuitry of the sensor **30** preferably includes a plurality of analog-to-digital (A/D) converters **180** as illustrated. Moreover, each of these A/D converters **180** may have a controllable scale. Scanning means **182** sequentially connects different elements to the bank of A/D converters **180**. The illustrated gain processor **185** provides range determining and setting means for controlling the range of the A/D converters **180** based upon prior A/D conversions to thereby provide enhanced conversion resolution. The A/D converters **180** may comprise the illustrated reference voltage input V_{ref} and offset voltage input V_{offset} for permitting setting of the range as would be readily appreciated by those skilled in the art. Accordingly, the range determining and setting means may also comprise a first digital-to-analog D/A converter **186** connected between the gain processor **185** and the reference voltage V_{ref} inputs of the A/D converters **180** as would also be readily understood by those skilled in the art. In addition, a second D/A converter **189** is also illustratively connected to the offset voltage inputs V_{offset} from the gain processor **185**.

The gain processor **185** may comprise histogram generating means for generating a histogram, as described above, and based upon prior A/D conversions. The graph adjacent the gain processor **185** in FIG. **12** illustrates a typical histogram plot **191**. The histogram plot **191** includes two peaks corresponding to the sensed ridges and valleys of the fingerprint as would be readily appreciated by those skilled in the art. By setting the range for the A/D converters **180**, the peaks can be readily positioned as desired to thereby account for the variations discussed above and use the full resolution of the A/D converters **180**.

Turning additionally to FIG. **13**, the A/D converters **180** may include an associated input amplifier for permitting setting of the range. In this variation, the range determining and setting means may also comprise the illustrated gain processor **185**, and wherein the amplifier is a programmable gain amplifier (PGA) **187** connected to the processor. A digital word output from the gain processor **185** sets the gain of the PGA **187** so that full use of the resolution of the A/D converters **180** is obtained for best accuracy. A second digital word output from the gain processor **185** and coupled to the amplifier **187** through the illustrated D/A converter **192** may also control the offset of the amplifier as would also be readily appreciated by those skilled in the art.

The range determining and setting means of the gain processor **185** may comprise default setting means for setting a default range for initial ones of the fingerprint sensing elements. The automatic gain control feature of the present invention allows the D/A converters **180** to operate over their full resolution range to thereby increase the accuracy of the image signal processing.

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Other aspects, advantages, and features relating to sensing of fingerprints are disclosed in copending U.S. patent application Ser. No. 08/592,469 entitled "Electric Field Fingerprint Sensor and Related Methods", and U.S. patent application Ser. No. 08/671,430 entitled "Integrated Circuit Device Having an Opening Exposing the Integrated Circuit Die and Related Methods", both assigned to the assignee of the present invention, and the entire disclosures of which are incorporated herein by reference. In addition, many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A fingerprint sensor comprising:

a substrate;

a plurality of semiconductor devices on said substrate and defining active circuit portions;

a first metal layer on said substrate interconnecting predetermined ones of said plurality of semiconductor devices;

a first dielectric layer on said first metal layer;

a second metal layer on said first dielectric layer defining a ground plane;

a second dielectric layer on said second metal layer; and

a third metal layer on said second dielectric layer and comprising an array of electric field sensing electrodes connected to active circuit portions for generating signals related to a sensed fingerprint.

2. A fingerprint sensor according to claim **1** further comprising a third dielectric layer on said third metal layer.

3. A fingerprint sensor according to claim **1** further comprising a package surrounding said substrate and having an opening aligned with the array of electric field sensing electrodes.

4. A fingerprint sensor according to claim **3** further comprising a first external electrode carried by said package for contact by a finger.

5. A fingerprint sensor according to claim **4** further comprising excitation drive means connected between the ground plane and said first external electrode for generating electric fields between the electric field sensing electrodes and adjacent finger portions.

6. A fingerprint sensor according to claim **4** further comprising power control means for controlling operation of active circuit portions based upon sensing finger contact with said first external electrode.

7. A fingerprint sensor according to claim **6** wherein said power control means comprises wake-up means for only powering active circuit portions upon sensing finger contact with said first external electrode to thereby conserve power.

8. A fingerprint sensor according to claim **6** wherein said power control means further comprises protection means for grounding active circuit portions upon not sensing finger contact with said first external electrode.

9. A fingerprint sensor according to claim **3** further comprising finger charge bleed means for bleeding a charge from a finger upon contact therewith.

10. A fingerprint sensor according to claim **9** wherein said finger charge bleed means comprises:

a second external electrode carried by said package for contact by a finger;

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a charge bleed resistor connected between said second external electrode and an earth ground.

11. A fingerprint sensor according to claim 10 wherein said second external electrode comprises an electrically conductive movable cover for the opening in said package. 5

12. A fingerprint sensor according to claim 1 further comprising:

- a shield electrode adjacent each electric field sensing electrode; and
- an amplifier having an input connected to each electric field sensing electrode, and having an output connected to each respective shield electrode, said amplifier having an amplification gain greater than about one to thereby increase noise rejection.

13. A fingerprint sensor comprising:

- a substrate;
- a plurality of semiconductor devices adjacent said substrate and defining active circuit portions for generating an output related to a sensed fingerprint;
- 20 a package surrounding said substrate;
- a first external electrode carried by said package for contact by a finger; and
- power control means for controlling operation of active circuit portions based upon sensing finger contact with said first external electrode.

14. A fingerprint sensor according to claim 13 further comprising at least one conductive layer comprising an array of electric field sensing electrodes connected to active circuit portions. 30

15. A fingerprint sensor according to claim 14 further comprising excitation drive means connected to said first external electrode for generating electric fields between the electric field sensing electrodes and adjacent finger portions.

16. A fingerprint sensor according to claim 13 wherein said power control means comprises wake-up means for only powering active circuit portions upon sensing finger contact with said first external electrode to thereby conserve power.

17. A fingerprint sensor according to claim 13 wherein said power control means further comprises protection means for grounding active circuit portions upon not sensing finger contact with said first external electrode.

18. A fingerprint sensor according to claim 17 further comprising finger charge bleed means for bleeding a charge from a finger upon contact therewith, and wherein said finger charge bleed means and said protection means cooperate so that active circuit portions remain grounded until said bleed means bleeds the charge from the finger. 45

19. A fingerprint sensor according to claim 18 wherein said finger charge bleed means comprises:

- a second external electrode carried by said package for contact by a finger; and
- 55 a charge bleed resistor connected between said second external electrode and an earth ground.

20. A fingerprint sensor according to claim 19 wherein said second external electrode comprises an electrically conductive movable cover for said package.

21. A fingerprint sensor according to claim 19 wherein said at least one conductive layer comprises a ground plane layer connected to said charge bleed resistor.

22. A fingerprint sensor comprising:

- a substrate;
- a plurality of semiconductor devices adjacent said substrate and defining active circuit portions for generating an output related to a sensed fingerprint;

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a package surrounding said substrate;

finger charge bleed means for bleeding a charge from a finger upon contact therewith to protect the active circuit portions, said finger charge bleed means comprising a second external electrode carried by said package for contact by a finger and a charge bleed resistor connected between said second external electrode and an earth ground.

23. A fingerprint sensor according to claim 22 wherein said second external electrode comprises an electrically conductive movable cover for said package.

24. A fingerprint sensor according to claim 22 further comprising at least one conductive layer comprising an array of electric field sensing electrodes connected to the active circuit portions.

25. A fingerprint sensor according to claim 24 further comprising:

- a first external electrode carried by said package; and
- excitation drive means connected to said first external electrode for generating electric fields between the electric field sensing electrodes and adjacent finger portions.

26. A fingerprint sensor comprising:

- a substrate;
- at least one electrically conductive layer adjacent said substrate and comprising portions defining an array of pairs of electric field sensing electrodes and associated shield electrodes; and
- a respective amplifier connected between each pair of electric field sensing electrodes and associated shield electrodes, each amplifier having an amplification gain greater than about one to thereby increase noise rejection.

27. A fingerprint sensor according to claim 26 wherein each amplifier has an input connected to each electric field sensing electrode and has an output connected to each respective shield electrode.

28. A fingerprint sensor according to claim 26 further comprising a plurality of semiconductor devices adjacent said substrate and defining the amplifiers.

29. A method for making a fingerprint sensor comprising the steps of:

- forming a plurality of semiconductor devices on a substrate and defining active circuit portions;
- forming a first metal layer on the substrate interconnecting predetermined ones of the plurality of semiconductor devices;
- forming a first dielectric layer on the first metal layer;
- forming a second metal layer on the first dielectric layer defining a ground plane;
- forming a second dielectric layer on the second metal layer; and
- forming a third metal layer on the second dielectric layer and comprising an array of electric field sensing electrodes connected to active circuit portions for generating signals related to a sensed fingerprint.

30. A method according to claim 29 further comprising the step of forming a third dielectric layer on the third metal layer.

31. A method according to claim 29 further comprising the step of forming a package surrounding the substrate and having an opening aligned with the array of electric field sensing electrodes.

32. A method according to claim 31 further comprising the step of forming a first external electrode carried by the package for contact by a finger.

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33. A method according to claim **31** further comprising the steps of:

forming a second external electrode carried by the package for contact by a finger; and

connecting a charge bleed resistor between the second external electrode and an earth ground.

34. A method for controlling operation of a fingerprint sensor of a type comprising a plurality of semiconductor devices on a substrate and defining active circuit portions for generating an output related to a sensed fingerprint, a package surrounding the substrate, a first external electrode carried by the package for contact by a finger, and power control means positioned on the substrate and connected to the active circuit portions, the method comprising the steps of:

only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power; and

grounding active circuit portions upon not sensing finger contact with the first external electrode.

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35. A method according to claim **34** further comprising the step of bleeding a charge from the finger upon initial contact of the finger with the fingerprint package and before switching from grounding of the active circuit portions to powering same.

36. A method of increasing noise rejection in a fingerprint sensor of a type comprising a substrate, and at least one electrically conductive layer adjacent said substrate and comprising portions defining an array of electric field sensing electrodes, the method comprising the steps of:

forming a shield electrode for each respective electric field sensing electrode;

forming a respective amplifier connected between each pair of electric field sensing electrodes and associated shield electrodes; and

operating each amplifier at an amplification gain greater than about one to thereby increase noise rejection.

* * * * *

EXHIBIT D



US005963679A

United States Patent [19]

Setlak

[11] Patent Number: **5,963,679**
 [45] Date of Patent: ***Oct. 5, 1999**

[54] **ELECTRIC FIELD FINGERPRINT SENSOR APPARATUS AND RELATED METHODS**

[75] Inventor: **Dale R. Setlak**, Melbourne, Fla.

[73] Assignee: **Harris Corporation**, Melbourne, Fla.

[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

[21] Appl. No.: **08/592,469**

[22] Filed: **Jan. 26, 1996**

[51] Int. Cl.⁶ **G06K 7/00**; G06K 9/00

[52] U.S. Cl. **382/312; 382/124; 382/115**

[58] Field of Search 382/312, 324, 382/124-127, 321, 115, 223, 274, 261, 270, 275, 205, 211; 283/78; 73/862.046

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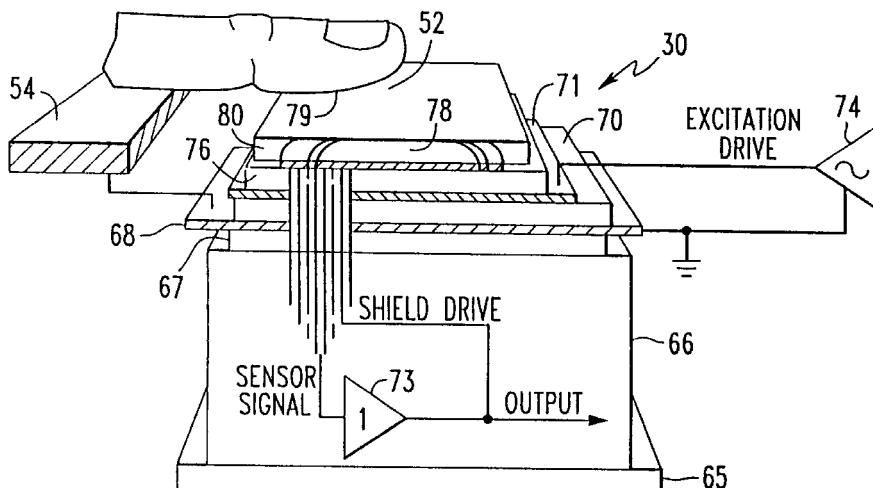
Attorney, Agent, or Firm—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A. Attorneys at Law

[57]

ABSTRACT

A fingerprint sensor includes an array of electric field sensing electrodes, a dielectric layer on the sensing electrodes with the dielectric layer for receiving a finger adjacent thereto, and a driver for applying an electric field drive signal to the sensing electrodes and adjacent portions of the finger so that the sensing electrodes produce a fingerprint image output signal. In one embodiment of the invention, the driver provides a coherent drive signal for the array. A respective shield electrode may be associated with each of the electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes. Each shield electrode may be actively driven for further shielding. The fingerprint sensor preferably further includes a synchronous demodulator and contrast enhancer for more accurate output image signals. The fingerprint sensor may be effectively used to control access to a computer workstation. Method aspects are also disclosed.

51 Claims, 10 Drawing Sheets



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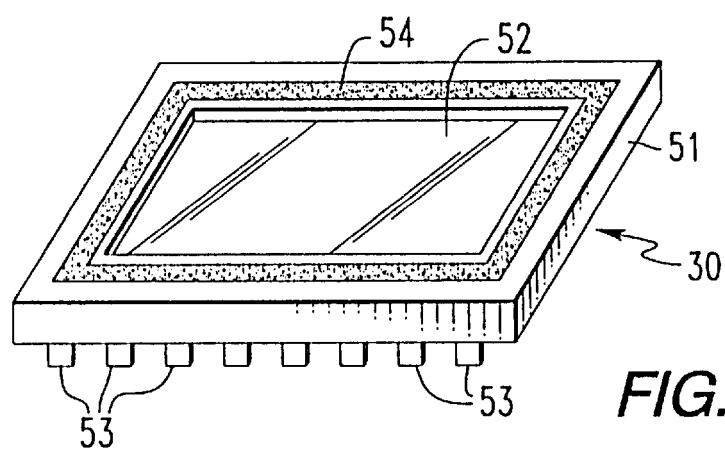
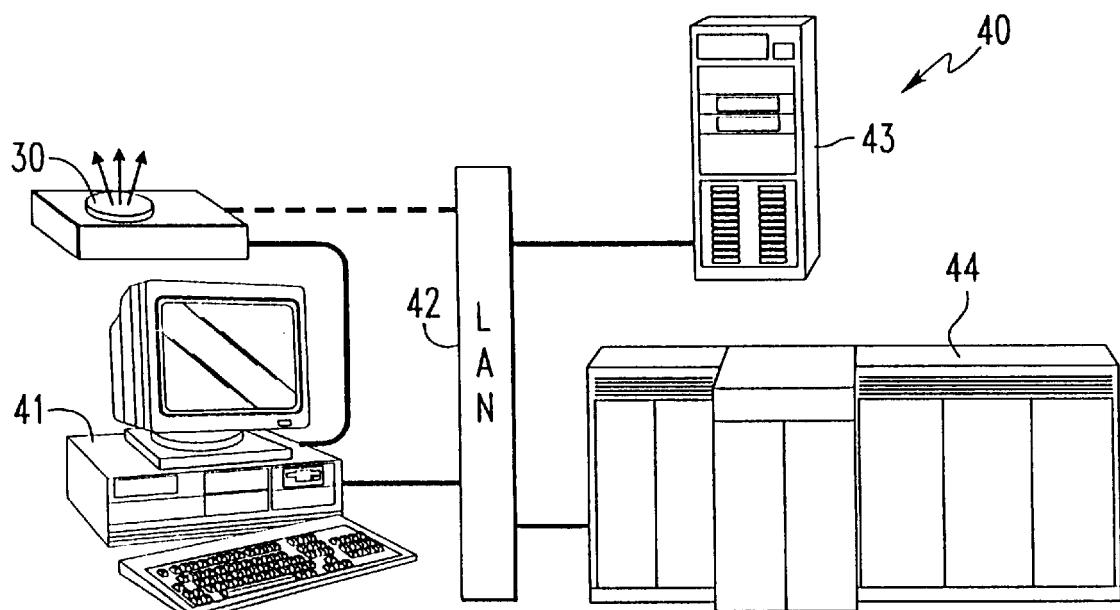
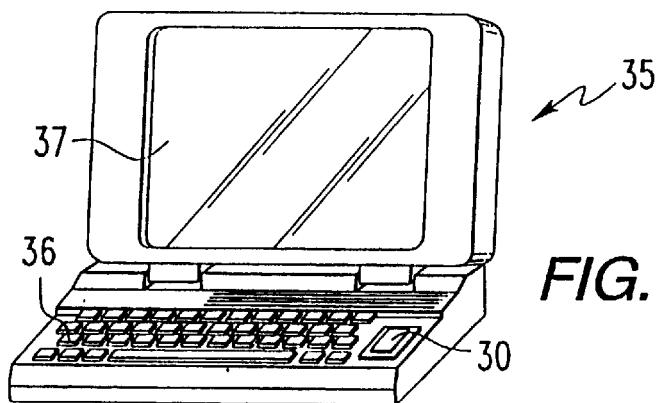
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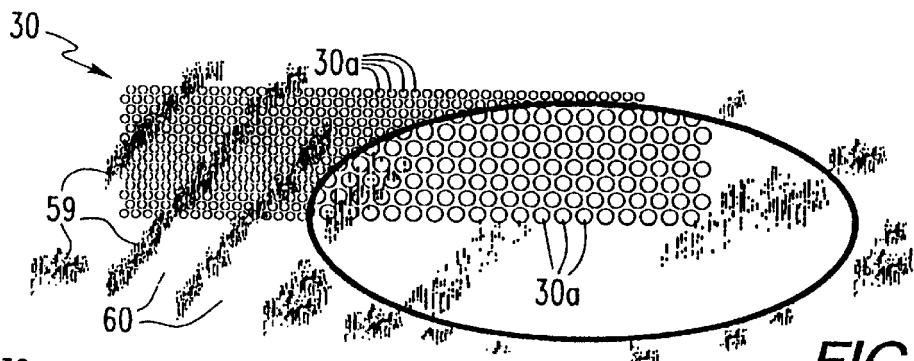


FIG. 4

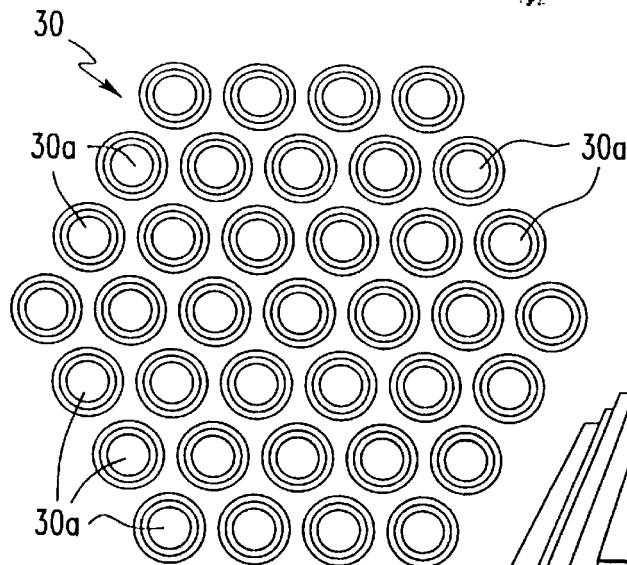


FIG. 5

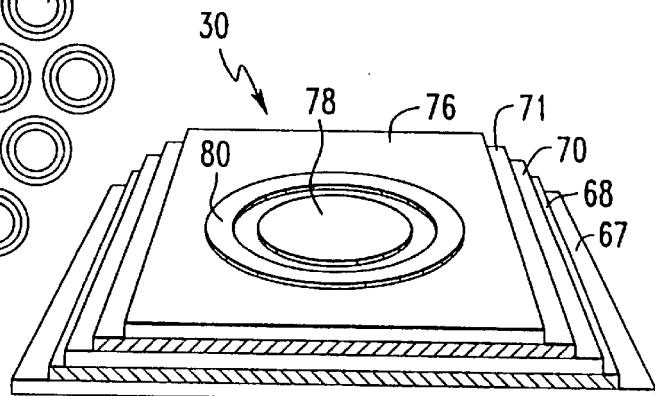


FIG. 6

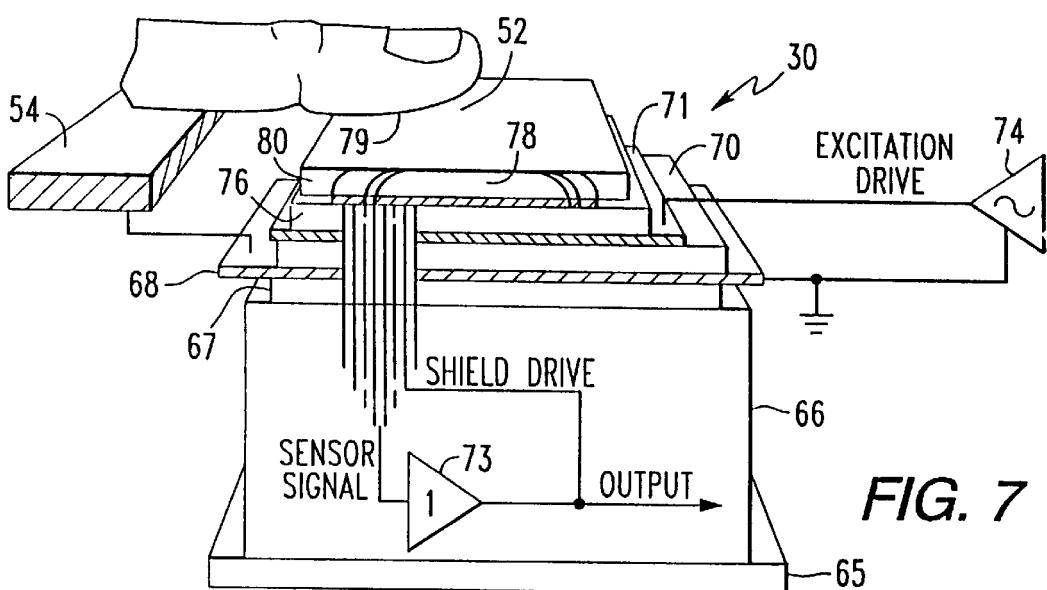
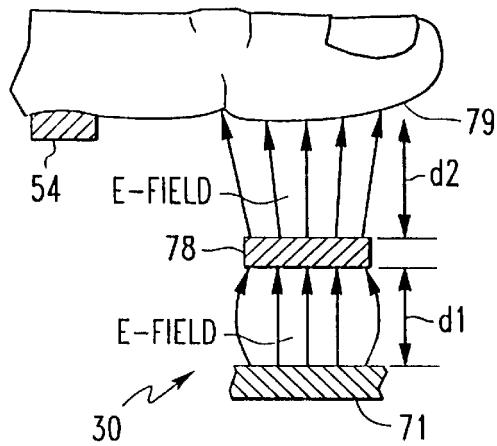
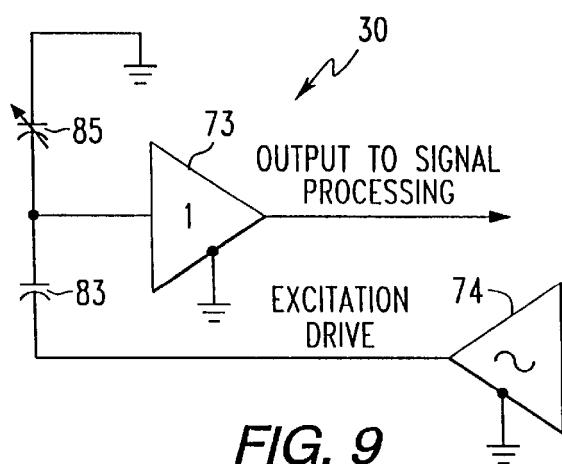
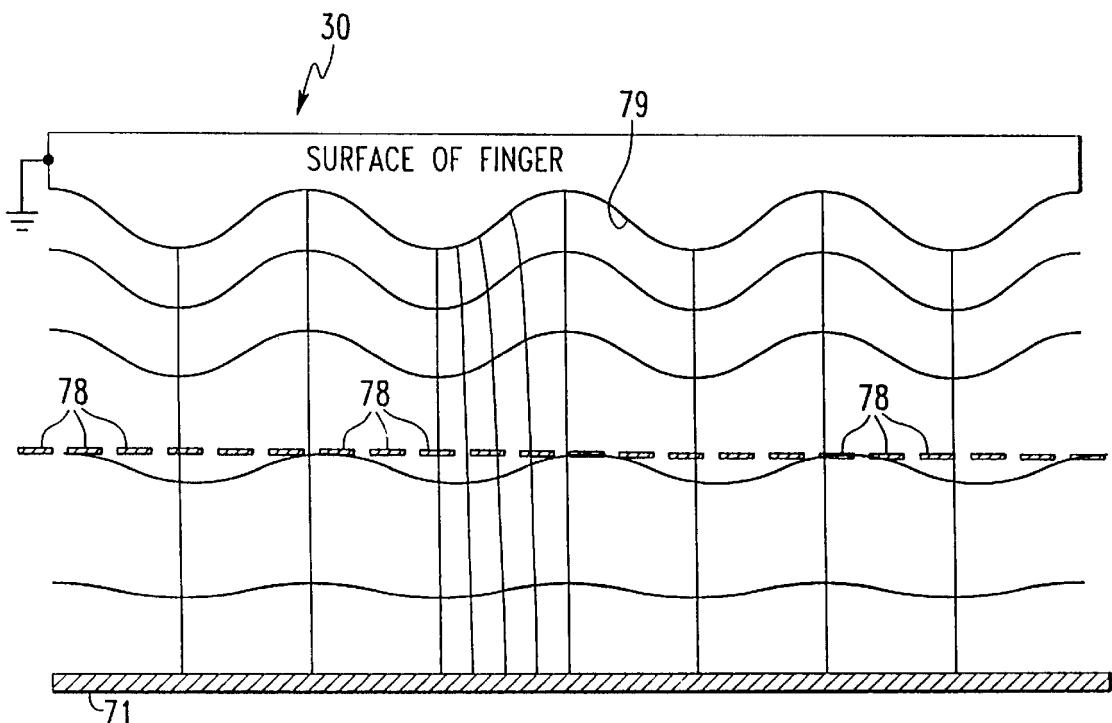


FIG. 7

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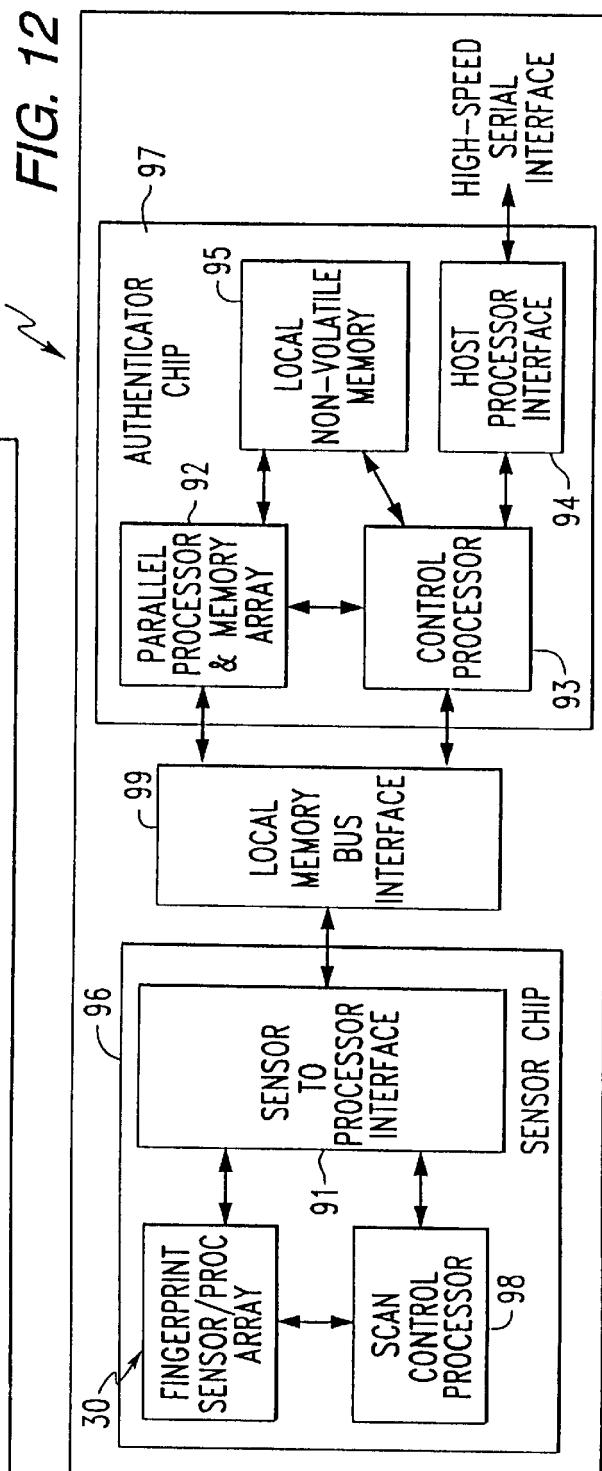
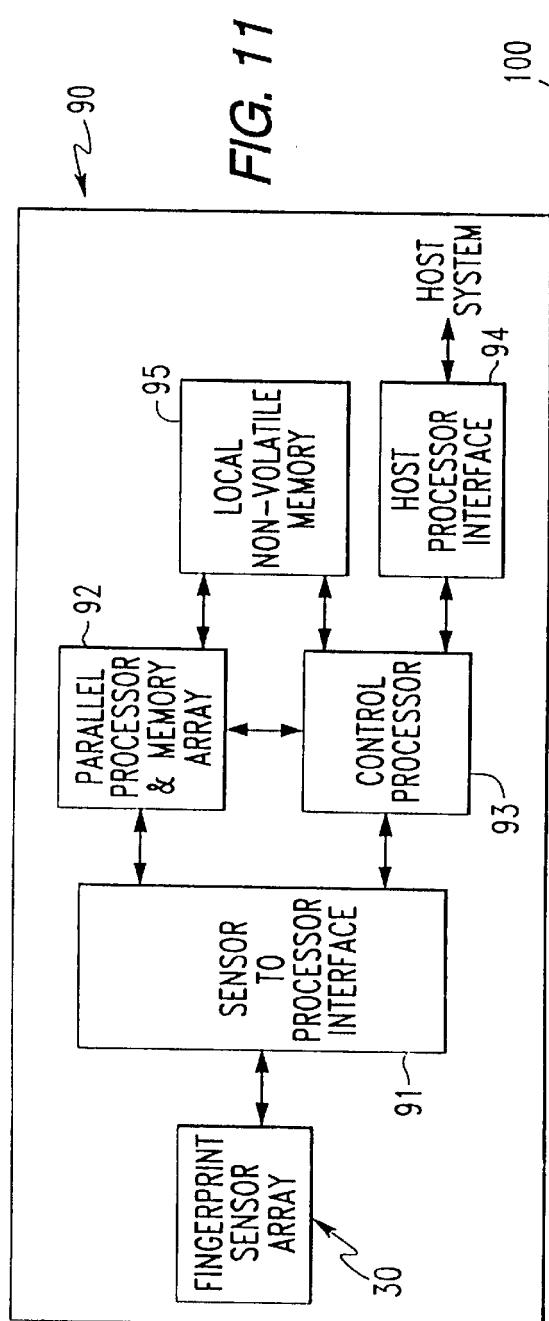
5,963,679**FIG. 8****FIG. 9****FIG. 10**

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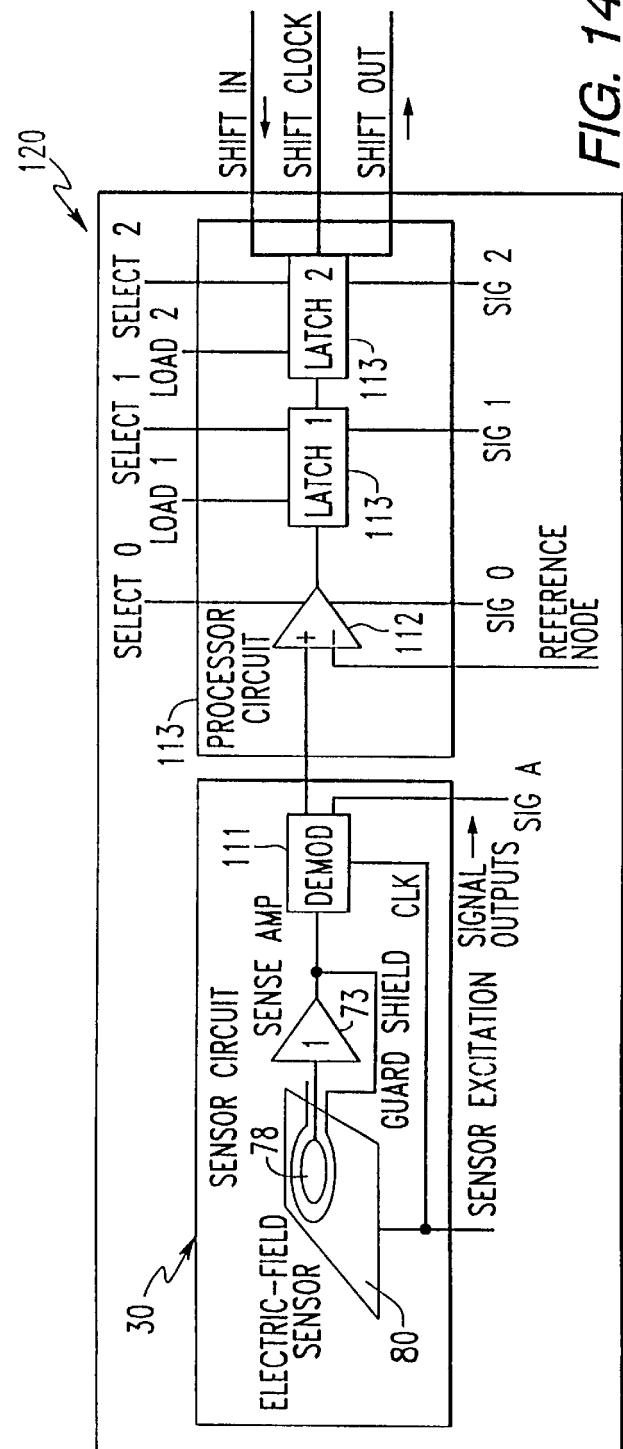
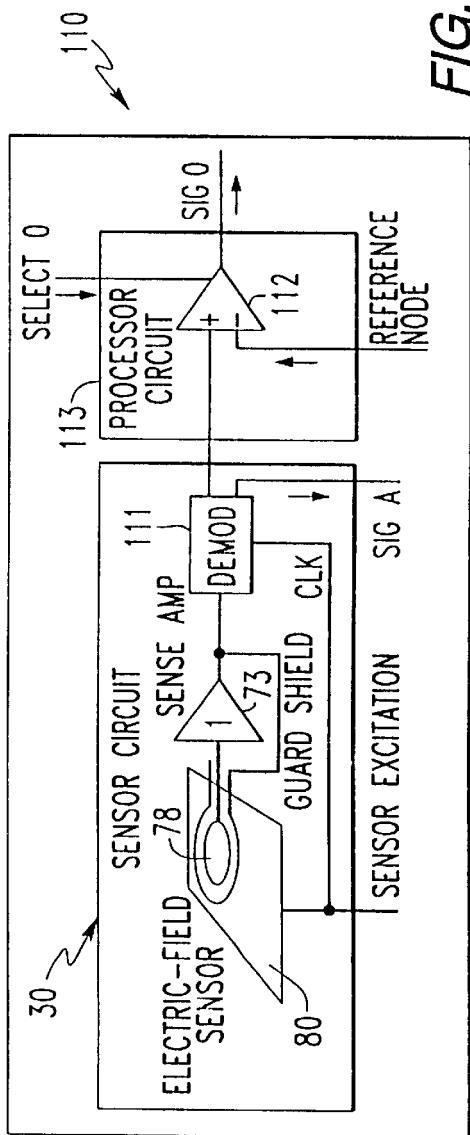


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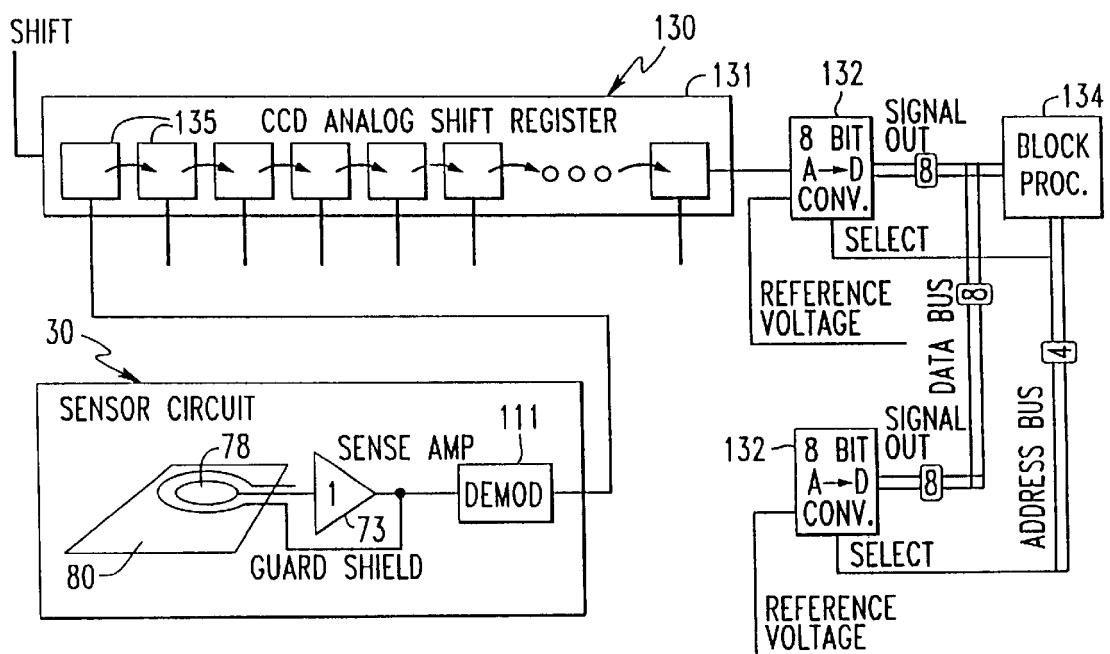
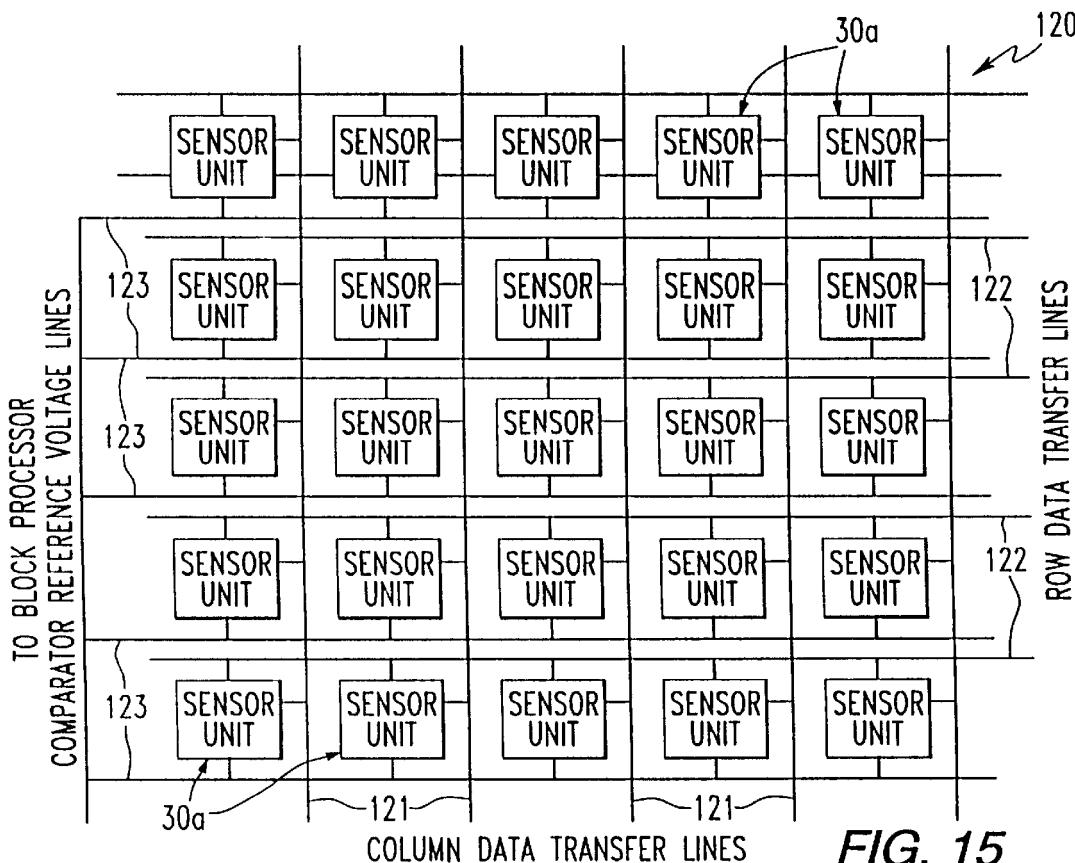


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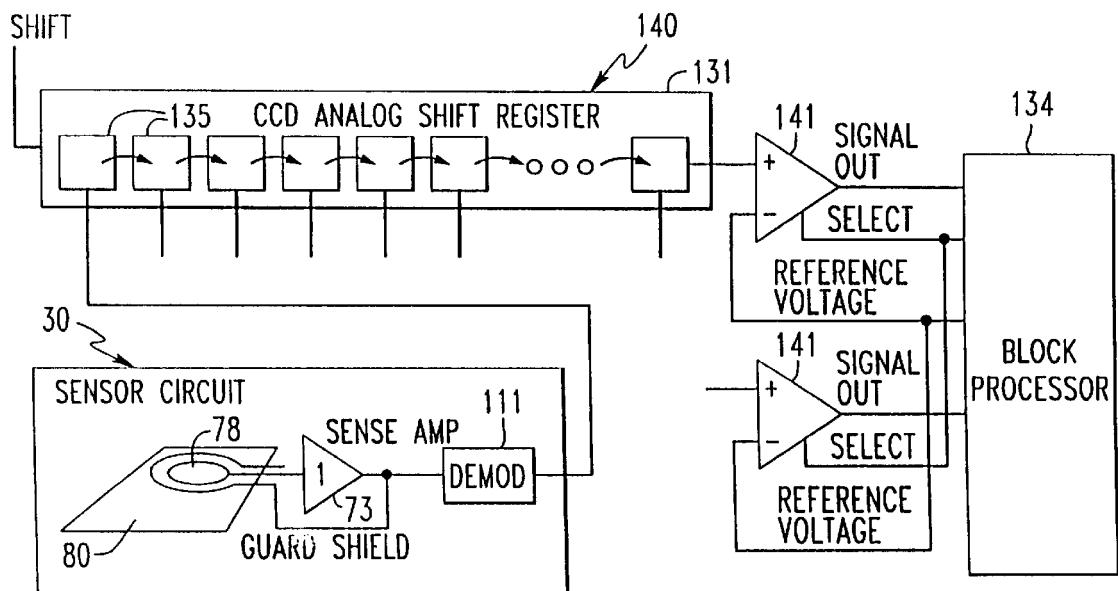


FIG. 17

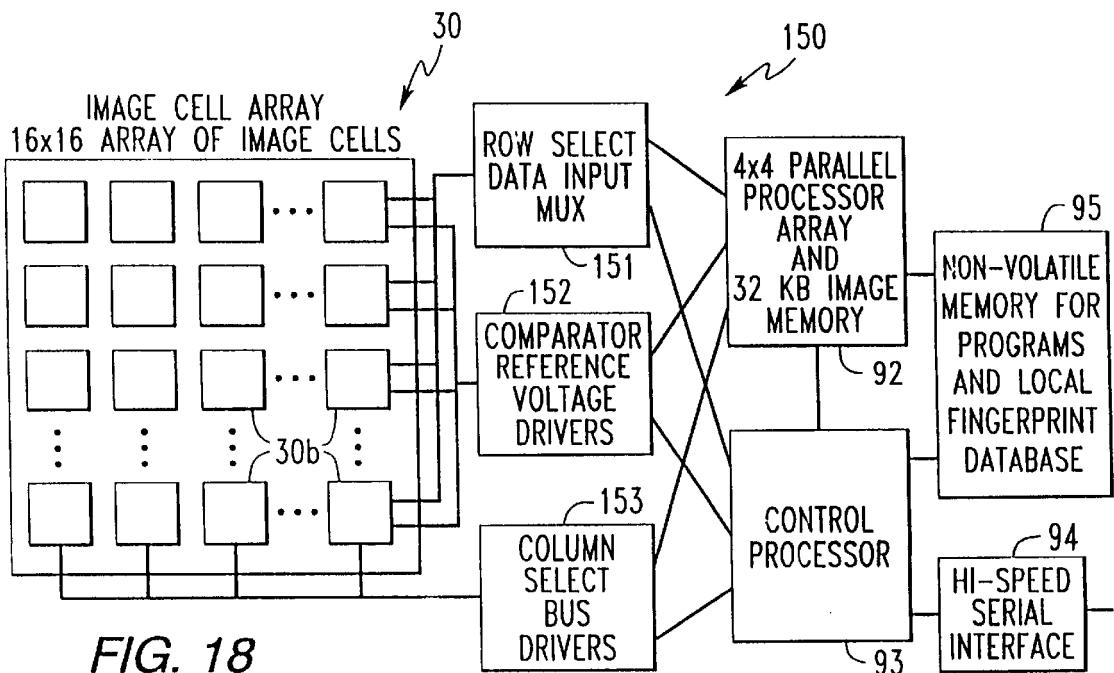


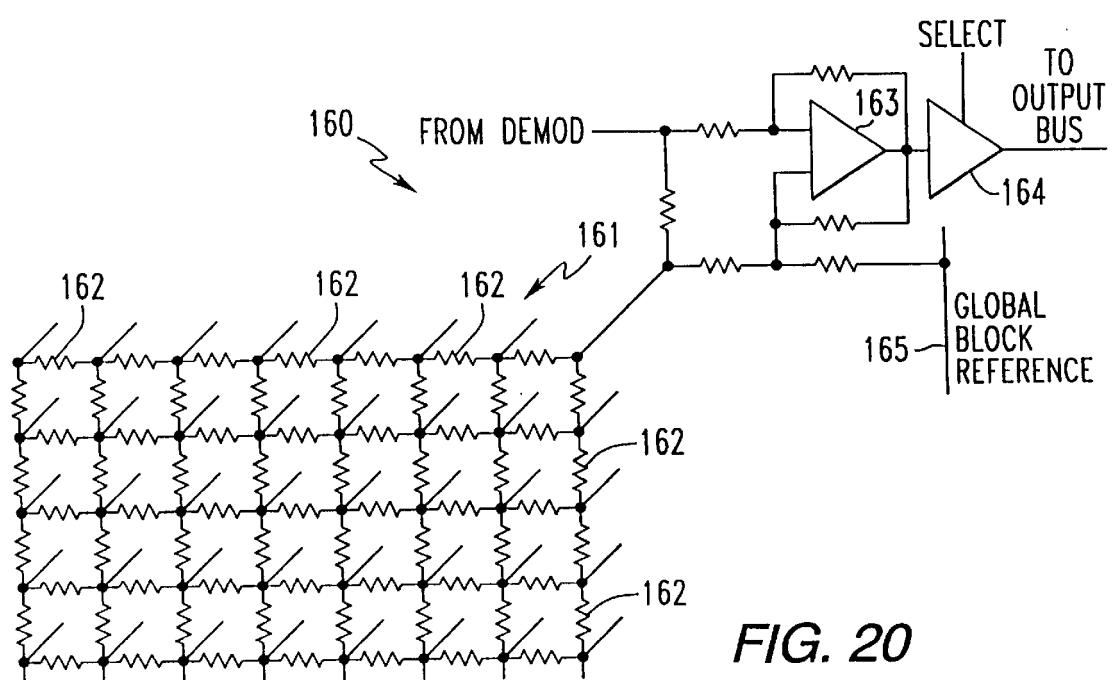
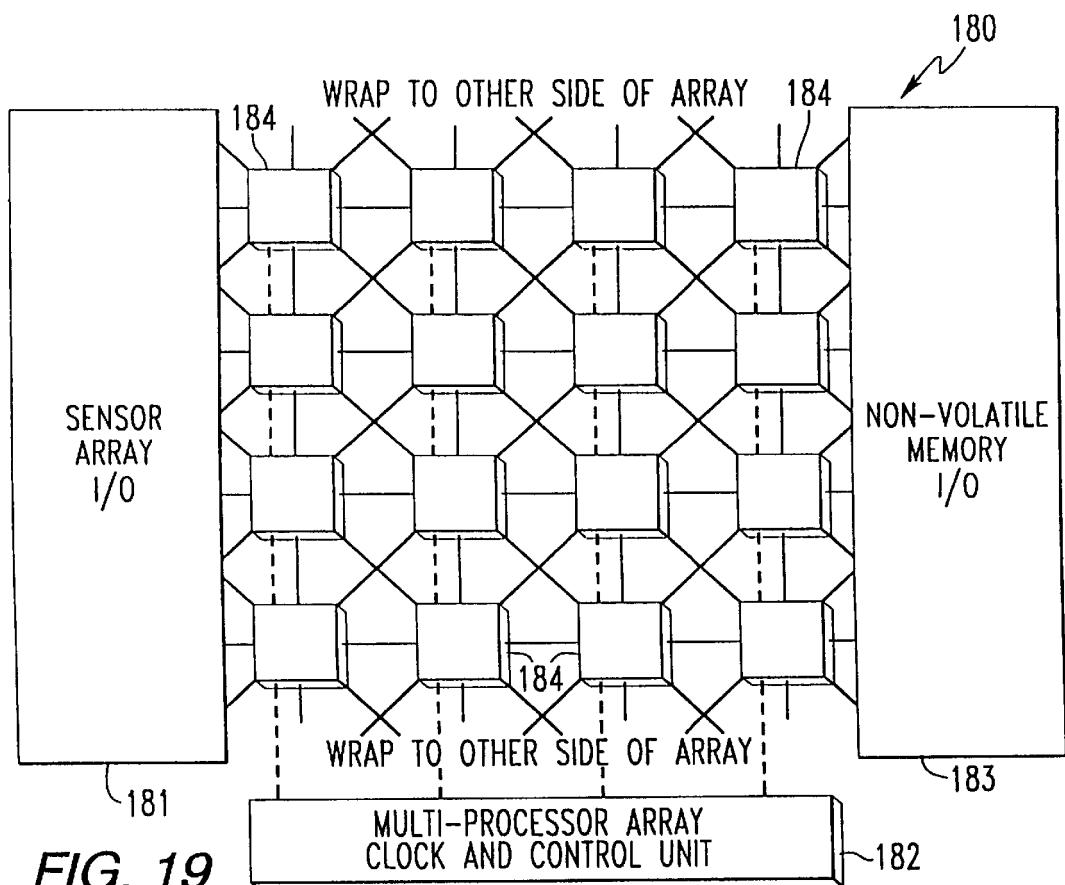
FIG. 18

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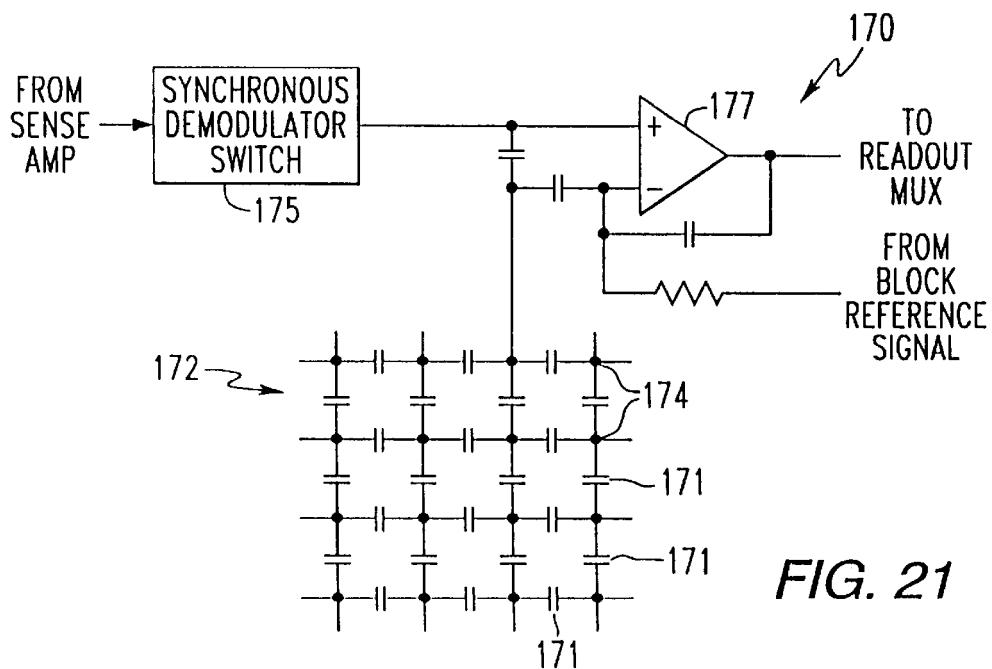


FIG. 21

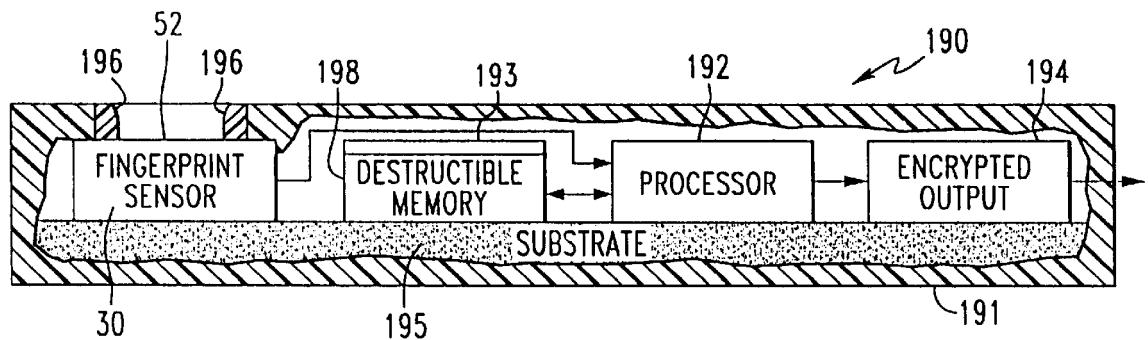


FIG. 22

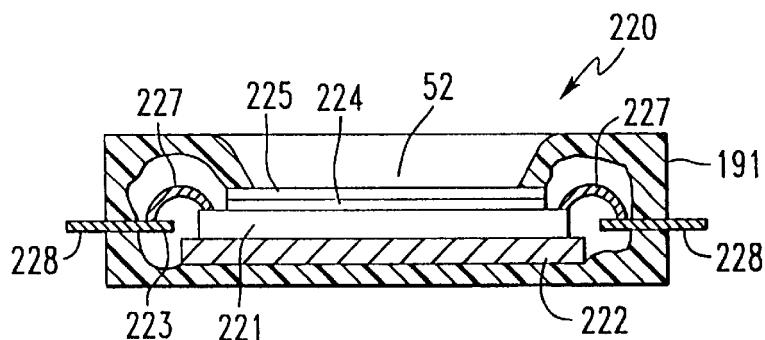


FIG. 23

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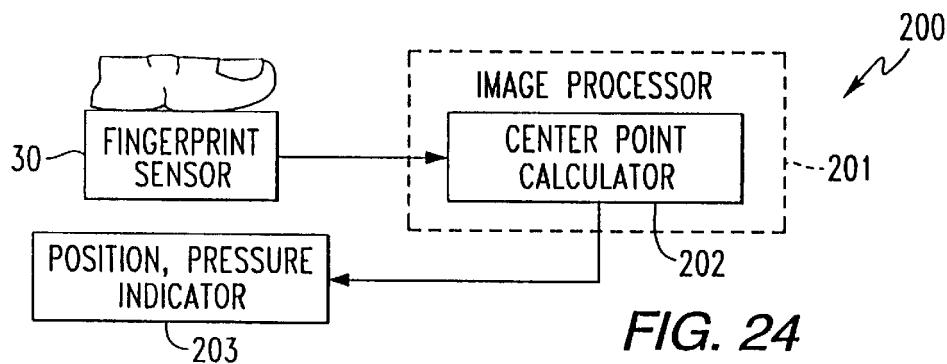


FIG. 24

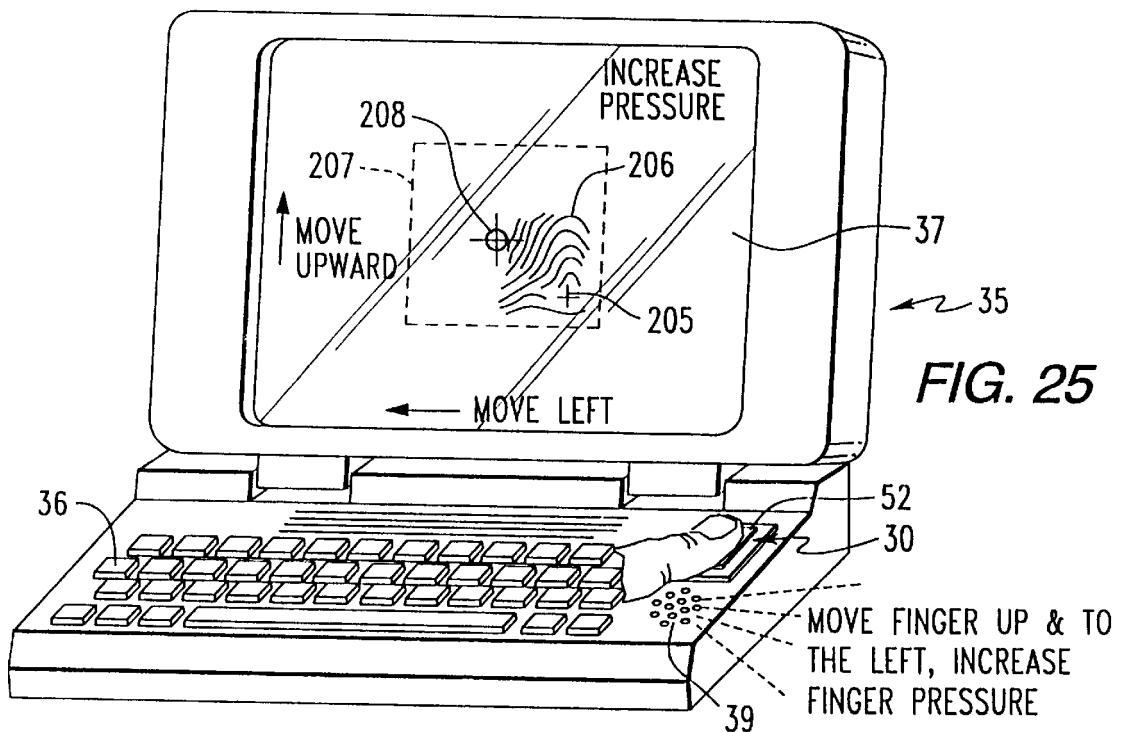


FIG. 25

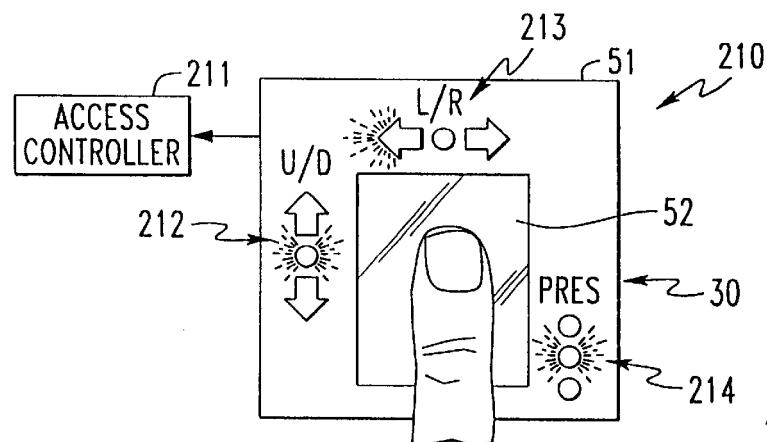


FIG. 26

ELECTRIC FIELD FINGERPRINT SENSOR APPARATUS AND RELATED METHODS

FIELD OF THE INVENTION

The present invention relates to the field of personal identification and verification, and, more particularly, to the field of fingerprint sensing and processing.

BACKGROUND OF THE INVENTION

Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. In particular, a common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in storage to determine proper identification of a person, such as for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. For example, U.S. Pat. No. 4,210,899 to Swonger et al. discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. U.S. Pat. No. 4,525,859 to Bowles similarly discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. In addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams. Accordingly, optical sensors may thus be bulky and be susceptible to shock, vibration and surface contamination. Accordingly, an optical fingerprint sensor may be unreliable in service in addition to being bulky and relatively expensive due to optics and moving parts.

In the event of a failure to form an acceptable image of a fingerprint, U.S. Pat. No. 4,947,443 to Costello, for example, discloses a series of indicator lights which give the user a simple go or no-go indication of the acceptability of the fingerprint scanning among other potential system identification failures. In other words, another shortcoming of conventional fingerprint sensors is that inaccurate positioning of the finger relative to the sensor may reduce the ability of the processor to accurately and quickly determine a match between a sample fingerprint and a plurality of reference fingerprints.

U.S. Pat. No. 4,353,056 to Tsikos discloses another approach to sensing a live fingerprint. In particular, the patent discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques. Unfortunately, the resilient materials required for the sensor

may suffer from long term reliability problems. In addition, multiplexing techniques for driving and scanning each of the individual capacitors may be relatively slow and cumbersome. Moreover, noise and stray capacitances may adversely affect the plurality of relatively small and closely spaced capacitors.

U.S. Pat. No. 5,325,442 to Knapp discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying portion of the finger surface which, in turn, is at ground potential. The sensor may be fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes. Further conductors may be provided on the surface of the dielectric material remote from the sensing electrodes and extending over regions between the sensing electrodes, for example, as lines or in grid form, which conductors are grounded in order to improve the electrical contact to the finger surface.

Unfortunately, driving the array of closely spaced sensing electrodes as disclosed in the Knapp et al. patent may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. Yet another difficulty with such a sensor, as with many optical sensors, is that different portions of the fingerprint may require relatively complicated post image collection processing to provide for usable signal levels and contrast to thereby permit accurate determination of the ridges and valleys of the fingerprint.

Yet another shortcoming of conventional fingerprint sensors is that the leads and internal components of a conventional fingerprint sensor, either optical, ultrasonic or capacitive, may be tampered with, such as to send a false acceptance signal to an associated portion of equipment. Accordingly, even if the sensor is accurate and reliable, it may be readily bypassed to gain access or entry to the equipment or area intended to be protected by the fingerprint sensor.

Greater advances in fingerprint sensing and matching for identification and verification are desirable and may prevent unauthorized use of computer workstations, appliances, vehicles, and confidential data. Inexpensive and effective fingerprint identification may also be used at point-of-sale terminals, and ensure further security of credit and debit cards, firearms, and provide a personal electronic signature. Unfortunately, current sensors and their associated circuitry may be too bulky, expensive and unreliable for a great many applications which would otherwise benefit from fingerprint identification and verification technology.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a fingerprint sensor and related methods for accurately sensing a fingerprint, and which sensor is rugged, compact, reliable and relatively inexpensive.

These and other objects, features and advantages according to the invention are provided by a fingerprint sensor comprising an array of electric field sensing electrodes, a dielectric layer on the electric field sensing electrodes with

the dielectric layer for receiving a finger adjacent thereto, and drive means for applying an electric field drive signal to the electric field sensing electrodes and adjacent portions of the finger so that the electric field sensing electrodes produce a fingerprint image output signal. Accordingly, the many shortcomings and disadvantages of prior art optical sensors are thus overcome, as the sensor in accordance with the present invention may be readily made to be rugged, compact, relatively low cost, and accurate.

In one advantageous embodiment of the invention the drive means preferably comprises coherent drive means for driving the array with a coherent signal. More particularly, the coherent drive means may include a drive electrode adjacent the electric field sensing electrodes, a second dielectric layer between the drive electrode and the electric field sensing electrodes, and a drive circuit for powering the drive electrode to generate the coherent electric field drive signal with a predetermined frequency. The sensor also preferably includes a finger electrode positioned adjacent the dielectric layer for contact with the finger.

Another important embodiment and aspect of the invention includes a respective shield electrode associated with each of the electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes. Each shield electrode may be provided by an electrically conductive layer surrounding a respective sensing electrode with a dielectric layer therebetween. To further reduce the driving requirement for each sensing electrode and reduce the undesirable effects of adjacent electrodes, the fingerprint sensor preferably further comprises active shield driving means for actively driving each of the shield electrodes. The active shield driving means may be provided by an amplifier operatively connected to each electric field sensing electrode and each shield electrode for actively driving the shield electrode with a portion of an output signal from the amplifier.

Yet another significant aspect of the invention addresses the difficulty of variation in finger conductivity and contamination. More particularly, the fingerprint sensor preferably further includes synchronous demodulator means operatively connected to the electric field sensing electrodes for synchronously demodulating signals therefrom so that sensitivity to variations in conductivity is reduced.

Still another significant aspect of the present invention relates to image contrast and uniformity enhancement which has typically been attempted via complicated and relatively slow downstream software driven processing of a fingerprint image signal. The present invention advantageously includes dynamic contrast enhancing means operatively connected to the electric field sensing electrodes and within the integrated circuit of the sensor for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

In one embodiment, the dynamic contrast enhancing means may be provided by a capacitor matrix operatively connected to the electric field sensing electrodes, and an alternating current (AC) capacitor matrix drive means for driving the capacitor matrix. In addition, the AC capacitor matrix drive means may be provided, in part, by the synchronous demodulator described above. In an alternate embodiment, the dynamic contrast enhancing means may comprise a resistor array or matrix operatively connected to the electric field sensing electrodes.

The fingerprint sensor may desirably be implemented using semiconductor processing techniques and wherein the upper dielectric layer, upon which the finger is placed, is an

upper exposed portion of the semiconductor chip containing the sensing and drive electrodes, as well as associated active electronic circuitry. In particular, an amplifier may be operatively connected to each electric field sensing electrode, and multiplexing means provided for selectively reading each of the electric field sensing electrodes. The sensor may also preferably include package means in one embodiment for enclosing the substrate, the active semiconductor layer, the electric field sensing electrodes, and the dielectric layer. The package means preferably has an opening therethrough in registry with the dielectric layer.

The fingerprint sensor may be used in many applications. In one preferred application the sensor is used in combination with a computer workstation, such as a fixed workstation or a portable notebook computer. In other words, the computer workstation preferably comprises a housing, a computer processor positioned within the housing, a display operatively connected to the computer processor, a keyboard operatively connected to the computer processor, and fingerprint sensor means mounted within and protected by the housing and operatively connected to the computer processor.

Moreover, the fingerprint sensor may interface with the computer processor so that the electronics associated with the sensor may be simplified and their expense thereby reduced. Thus, the computer processor preferably comprises access control means for permitting operation of the computer workstation only upon determining a match between a fingerprint sensed by the protectively mounted fingerprint sensor and an authorized reference fingerprint. The fingerprint sensor may be the electric field fingerprint sensor described herein or other sensors may be used.

Method related aspects of the invention are also disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of the fingerprint sensor in combination with a notebook computer in accordance with the present invention.

FIG. 2 is a schematic diagram of the fingerprint sensor in combination with a computer workstation and associated information processing computer and local area network (LAN) in accordance with the present invention.

FIG. 3 is a schematic perspective view of an embodiment of a fingerprint sensor in accordance with the invention.

FIG. 4 is a schematic plan view of a portion of the sensor and an overlying fingerprint pattern in accordance with the present invention with a portion thereof greatly enlarged for clarity of illustration.

FIG. 5 is a greatly enlarged plan view of a portion of the fingerprint sensor in accordance with the invention with the upper dielectric layer removed therefrom for clarity of illustration.

FIG. 6 is a schematic perspective view of a portion of the fingerprint sensor in accordance with the present invention.

FIG. 7 is a schematic fragmentary view of a portion of the fingerprint sensor in accordance with the present invention.

FIG. 8 is a schematic side view, partially in section, illustrating the electric fields in accordance with the present invention.

FIG. 9 is a schematic circuit diagram of a portion of the fingerprint sensor in accordance with the present invention.

FIG. 10 is an enlarged schematic side view, partially in section, further illustrating the electric fields in accordance with the present invention.

FIG. 11 is a schematic block diagram of the fingerprint sensor and associated circuitry in one embodiment in accordance with the present invention.

FIG. 12 is a schematic block diagram of the fingerprint sensor and associated circuitry in another embodiment in accordance with the present invention.

FIG. 13 is a schematic block diagram of an embodiment of a sensor circuit in accordance with the present invention.

FIG. 14 is a schematic block diagram of another embodiment of a sensor circuit in accordance with the present invention.

FIG. 15 is a schematic block diagram illustrating a plurality of sensor units in accordance with the present invention.

FIG. 16 is a schematic block diagram of an embodiment of a portion of the signal processing for the fingerprint sensor in accordance with the present invention.

FIG. 17 is a schematic block diagram of another embodiment of a portion of the signal processing for the fingerprint sensor in accordance with the present invention.

FIG. 18 is a schematic block diagram of yet another embodiment of signal processing circuitry for the fingerprint sensor in accordance with the present invention.

FIG. 19 is a schematic circuit diagram of yet another embodiment of a portion of the signal processing for the fingerprint sensor in accordance with the present invention.

FIG. 20 is a schematic circuit diagram of yet another embodiment of a portion of the signal processing for the fingerprint sensor in accordance with the present invention illustrating a resistor matrix for dynamic contrast enhancement.

FIG. 21 is a schematic circuit diagram of yet another embodiment of a portion of the signal processing for the fingerprint sensor in accordance with the present invention illustrating a capacitor matrix implementation for dynamic contrast enhancement.

FIG. 22 is a schematic block diagram of an embodiment of the fingerprint sensor package in accordance with the present invention.

FIG. 23 is a schematic diagram of another embodiment of the fingerprint sensor package in accordance with the present invention.

FIG. 24 is a schematic block diagram of another aspect of the sensor for illustrating near real-time positioning feedback of finger placement in accordance with the invention.

FIG. 25 is a schematic perspective diagram of a computer illustrating near real-time positioning feedback of finger placement in accordance with the present invention.

FIG. 26 is a schematic perspective diagram of a fingerprint sensor including indicators for illustrating near real-time positioning feedback of finger placement in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements

throughout. The scaling of various features, particularly fingers and layers in the drawing figures, have been exaggerated for clarity of explanation.

Referring first to FIGS. 1-3, the fingerprint sensor 30 in accordance with the invention is initially described. The illustrated sensor 30 includes a housing or package 51, a dielectric layer 52 exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of signal conductors 53. A conductive strip or electrode 54 around the periphery of the dielectric layer 52 also provides a contact electrode for the finger as described in greater detail below. The sensor 30 may provide output signals in a range of sophistication levels depending on the level of processing incorporated in the package as also described in greater detail below.

The fingerprint sensor 30 may be used in many different applications as will be readily appreciated by those skilled in the art, such as for personal identification or verification purposes. For example, the sensor 30 may be used to permit access to a computer workstation, such as a notebook computer 35 including a keyboard 36 and associated folding display screen 37 (FIG. 1). In other words, user access to the information and programs of the notebook computer 35 may only be granted if the desired fingerprint is first sensed as also described in greater detail herein.

Another application of the fingerprint sensor 30 is illustrated with particular reference to FIG. 2. The sensor 30 may be used to grant or deny access to a fixed workstation 41 for a computer information system 40. The system may include a plurality of such workstations 41 linked by a local area network (LAN) 43, which in turn, is linked to a fingerprint identification server 43, and an overall central computer 44. Many other applications for the low cost and reliable electric field sensor 30 in accordance with the invention are contemplated by the invention and will be readily appreciated by those skilled in the art.

Referring now additionally to FIGS. 4-10, the sensor 30 is described in greater detail. The sensor 30 includes a plurality of individual pixels or sensing elements 30a arranged in array pattern as shown perhaps best in FIGS. 4 and 5. As would be readily understood by those skilled in the art, these sensing elements are relatively small so as to be capable of sensing the ridges 59 and intervening valleys 60 of a typical fingerprint (FIG. 4). As will also be readily appreciated by those skilled in the art, live fingerprint readings as from the electric field sensor 30 in accordance with the present invention may be more reliable than optical sensing, because the conduction of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate. In contrast, an optical sensor may be deceived by a readily prepared photograph or other similar image of a fingerprint, for example.

The sensor 30 includes a substrate 65, and one or more active semiconductive layers 66 thereon. A ground plane electrode layer 68 is above the active layer 66 and separated therefrom by an insulating layer 67. A drive electrode layer 71 is positioned over another dielectric layer 70 and is connected to an excitation drive amplifier 74. The excitation drive signal may be typically in the range of about 1 KHz to 1 MHz and is coherently delivered across all of the array. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor 30 may be reduced, while the reliability is increased.

Another insulating layer 76 is on the drive electrode layer 71, and an illustratively circularly shaped sensing electrode 78 is on the insulating layer 76. The sensing electrode 78

may be connected to sensing electronics 73 formed in the active layer 66 as schematically illustrated, and as would be readily appreciated by those skilled in the art.

An annularly shaped shield electrode 80 surrounds the sensing electrode 78 in spaced relation therefrom. As would be readily appreciated by those skilled in the art the sensing electrode 78 and its surrounding shield electrode 80 may have other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements 30a. The shield electrode 80 is an active shield which is driven by a portion of the output of the amplifier circuit 73 to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electrodes. Accordingly, the sensor 30 permits all of the sensing elements to be driven by a coherent drive signal in sharp contrast to prior art sensors which required that each sensing electrode be individually driven.

As understood with additional reference to FIGS. 8–10, the excitation electrode 71 generates a first electric field to the sensing electrode 78 and a second electric field between the sensing electrode 78 and the surface of the finger 79, over the distances d1 and d2, respectively. In other terms, a first capacitor 83 (FIG. 9) is defined between the excitation electrode 71 and the sensing electrode 78, and a second capacitor 85 is defined between the finger skin 79 and ground. The capacitance of the second capacitor 85 varies depending on whether the sensing electrode 78 is adjacent a ridge or valley. Accordingly, the sensor 30 can be modeled as a capacitive voltage divider. The voltage sensed by the unity gain voltage follower or amplifier 73 will change as the distance d2 changes.

In general, the sensing elements 30a operate at very low currents and at very high impedances. For example, the output signal from each sensing electrode 78 is desirably about 5 to 10 millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element 30a, as defined by the outer dimensions of the shield electrode 80, may be about 0.002 to 0.005 inches in diameter. The excitation dielectric layer 76 and surface dielectric layer 52 may desirably have a thickness in the range of about 1 μm . The ground plane electrode 68 shields the active electronic devices from the excitation electrode 71. A relatively thick dielectric layer 67 will reduce the capacitance between these two structures and thereby reduce the current needed to drive the excitation electrode. The various signal feedthrough conductors for the electrodes 78, 80 to the active electronic circuitry may be readily formed as would be understood by those skilled in the art. In addition, the illustrated signal polarities may be readily reversed as would also be readily understood by those skilled in the art.

The overall contact or sensing surface for the sensor 30 may desirably be about 0.5 by 0.5 inches—a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor 30 in accordance with the invention is also fairly tolerant of dead pixels or sensing elements 30a. A typical sensor 30 includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor 30 may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

Referring now additionally to FIG. 11, functional partitioning of an apparatus 90 including the fingerprint sensor 30 is described. The fingerprint sensor apparatus 90 may be

configured to provide one or more of displacement sensing of the fingerprint, provide an image present trigger, perform analog-to-digital conversion, provide full image capture and image integrity determination, provide contrast enhancement and normalization, and provide image binarization. In the illustrated embodiment, the sensor 30 is connected to a parallel processor and memory array 92, and control processor 93 via the illustrated interface 91. The parallel processor 92 may provide image quality and bad block determinations; provide edge enhancement and smoothing and thinning; generate ridge flow vectors, smooth the vectors and generate ridge flow characteristics as may be desired for fingerprint matching; identify the center of the fingerprint; generate, smooth and clean curves; and provide minutiae identification. The illustrated control processor 93 may provide minutiae registration and matching, minutiae storage, generate authorization codes, and communicate with the host via the illustrated interface 94. The illustrated local non-volatile memory 95 may also be included in the apparatus 90.

A variation of the apparatus 90 of FIG. 11 is illustrated by the apparatus 100 of FIG. 12. This embodiment includes a two chip version of the sensor and processing electronics. The apparatus 100 includes a sensor chip 96 and an authenticator chip 97 connected via a local memory bus interface 99. A scan control processor 98 is also included in the illustrated embodiment of FIG. 12, while the remaining functional components are the same as in FIG. 11 and need no further description herein.

Demodulation and preliminary processing of the detected signals from the sensor 30 are further understood with reference to FIGS. 13 and 14. Both of the illustrated circuits 110, 120 desirably use an alternating current excitation. In addition, the amplitude of the voltage on the sensor is proportional to the displacement of the local ground plane, hence, the signal has to be demodulated before further use. FIG. 13 illustrates a local comparator 112 to allow the control to manage the A/D conversion process in parallel. The processor can present a sequence of a reference voltages to an entire row or column of pixels or sensor elements 30a and monitor the transitions on the SigO lines. A successive approximation conversion could be implemented, first stepping large steps, and then stepping in progressively finer steps over a smaller range, as would be readily understood by those skilled in the art. The SigO output can be a binary bus connection while the SigA output is a demodulated analog signal that can be used as part of analog reference voltage generating circuit, as would also be readily understood by those skilled in the art.

The circuit 120 illustrated in FIG. 14 has storage to do localized contrast enhancement for all sensor units or pixels simultaneously. The computation can use the analog comparator 112 for a decision element. The binarized output image can be shifted out of the binary shift registers provided by the illustrated latches 113. Alternately, the output image could be read out as with conventional memory array addressing as would be readily understood by those skilled in the art. Since the circuit 120 has its own local memory, it does not need a separate set of buffers to store the pixel data.

Variations in skin conductivity and contamination may cause phase shift of the electric field signal. Accordingly, the processing electronic circuits 110, 120 of FIGS. 13 and 14 preferably include a synchronous demodulator or detector 111 so that the overall circuit has less sensitivity to any such variations in conductivity.

Interconnections of the sensor units or pixels 30a in a portion of an array are schematically illustrated in FIG. 15.

Column data transfer lines 121, row data transfer lines 122, and comparator reference lines 123 are shown connected to the array of sensor units 30a. The interconnections may be desirably made in an 8-by-8 block of sensor units, although other configurations are also contemplated by the present invention.

Further embodiments of various processor circuitry is understood with reference to FIGS. 16 and 17. The circuit 130 of FIG. 16 includes a charge coupled device (CCD) shift register 131 which, in turn, includes a plurality of individual shift registers 135. The shift registers 131 function as a tapped delay line to facilitate image signal processing. The registers 135 feed respective A/D converters 132 operated under control of the illustrated block processor 134. The sensing amplifier outputs are connected to the CCD analog shift registers 135, with one shift register per row of pixels. A row of data is then shifted out of the register either to an A/D converter 132 which serves as the active conversion device. Each pixel is converted to an 8 bit digital word as it arrives at the converter. The conversion process and the A-to-D reference voltage are under control of block processors, where each block processor may control one or more rows, such as, for example, 16 rows per each processor. A limited degree of dynamic contrast compensation can be achieved using data from the previous pixel conversion to scale the reference voltage; however, significant downstream digital image processing may still be required.

The circuit 140 of FIG. 17 is similar to that of FIG. 16. In FIG. 17, a comparator 141 operates under control of the illustrated block processor 134 to provide the image output signals as would be readily understood by those skilled in the art.

Turning now additionally to FIG. 18, another aspect of the signal processing configurations in accordance with the invention is described. This circuit embodiment 150 is similar to that embodiment illustrated in FIG. 11 and described above. The circuit 150 of FIG. 18 illustratively includes a 16-by-16 array of sensor units or image cells 30b selectively addressed and read by the illustrated row select data input multiplexor 151, column select bus drivers 153, and comparator reference voltage dividers 152. Once an image has been captured from the electric field sensing electrodes and digitized, fingerprint features can be extracted from the image. FIG. 18 illustrates a high level view of a sensor connected to a bank of digital signal processors 92. A 128×128 pixel array, in this instance, has been partitioned into a 16×16 array of image cells 30b, wherein each image cell is formed of an 8×8 pixel array.

Each image cell 30b has a single comparator reference line that services the entire cell. When a cell 30b is being scanned, one of the parallel processors manages the reference voltage for that cell 30b and records the digitized signals for all of the sensors in that cell. During the process of scanning the sensors in the cell 30b, the processor can simultaneously correlate the data from the cell to generate a preliminary estimate of the ridge flow direction in that cell. In the illustrated embodiment, a control processor 93 manages the sensor signal scanning and digitization, and supervises a bank of parallel processors 92 that perform feature extraction and matching functions. The other illustrated components are similar to those discussed above with reference to FIG. 11 and, hence, need no further discussion.

Turning now additionally to FIG. 19, a 4×4 processor matrix circuit 180, such as might be used for a pipeline style implementation of the fingerprint minutiae processing, is illustrated. The circuit 180 includes an array of processors

184, a sensor array input/output portion 181, a non-volatile memory interface 183, and the illustrated multi-processor array clock and control unit 182. The illustrated circuit 180 may be used to identify and locate the fingerprint's unique minutiae to determine a match between a sensed fingerprint and one of a plurality of reference fingerprints. In other words, the processors 184 may match the minutiae against a set of previously stored reference minutia, to complete the identification process. When a positive identification has been made, for example, the circuit 180 may notify an external processor by sending an appropriately encrypted message over a host processor interface.

There is a general need to ensure sufficient contrast between the ridges and valleys of the fingerprint over the entire area of the fingerprint. The circuit 160 of FIG. 20 schematically illustrates a resistive network or matrix 161 including a plurality of interconnected resistors 162 for providing dynamic contrast enhancement for the array of pixels 30a. The effect of adjacent pixels is used to normalize the output of each pixel and while providing sufficient contrast. The circuit includes a pair of amplifiers 163, 164 for providing the enhanced contrast output signals.

Each pixel's value is determined by comparing the sensor signal to a reference signal that sums the block reference signal with a weighted average of the signals from all of the sensors in the immediate area. The square resistive grid or matrix provides the necessary weighted average to each of the pixel comparators simultaneously. The global block reference line 165 is preferably driven with a staircase waveform while the comparator outputs are monitored for change of state. Each pixel's gray-scale value may be determined by noting which step of the staircase causes that pixel's comparator to change state as would be readily understood by those skilled in the art.

A variation for dynamic contrast enhancement is understood with reference to the circuit 170 of FIG. 21. Dynamic contrast enhancement can also be implemented by an array 172 of capacitors 171 interconnecting the pixel nodes 174. In this embodiment, the array 172 receives an alternating current signal derived from the synchronous demodulator 175 described in greater detail above. The capacitors 171 serve as an AC impedance network distributing and averaging the AC signals in a fashion analogous to the behavior of the resistive network 161 (FIG. 20) for DC signals. In the AC contrast enhancing circuit 170, the lowpass filtering that in other embodiments may be part of the demodulator circuit, is moved to the comparator 177 circuit portion. The capacitor array 172 is readily implemented using conventional semiconductor processing techniques and may offer an advantage of relatively small size as compared to the resistor array implementation described above and as would be readily appreciated by those skilled in the art.

The resistive matrix circuit 160 and capacitor matrix circuit 170 may provide weighting for image contrast enhancement. An alternative is to conduct such enhancement via downstream software which may take a relatively long time to fully process.

Accordingly, the resistor matrix and capacitor matrix arrangement may provide greater overall processing speed. In addition, such preliminary processing at the sensor 30 may allow relaxation of A/D conversion from an 8 bit AD converter to a 1 bit converter in some embodiments, while still providing high speed and at a relatively low cost. For example, processing of the fingerprint image and determination of a match may desirably take only several seconds for certain applications to avoid user frustration.

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Referring now additionally to FIG. 22, another aspect of the invention is described wherein the sensor 30 may be contained within a secure sensor package 190. The sensor 30 is desirably mounted to prevent flexing or shifting which may stress the chip or its electrical connections. More particularly, the overall package may include a tamper resistant housing 191 as would be readily understood by those skilled in the art. For example, the housing 191 may be formed of a hard plastic material or metal that is strong and resistant to cutting, abrading or sawing. Alternately, the housing 191 may be a material which crumbles and destroys its internal circuit components if cutting, dissolution, or other forms of entry are attempted.

Those of skill in the art will appreciate other variations of tamper resistant housings 191 as contemplated by the present invention.

The sensor package 190 also includes the illustrated substrate 195, processor 192, destructible memory 195, and encrypted output circuit 194. More particularly, the encrypted output circuit 194 provides an output signal that can only be decrypted by the intended downstream device. Such encryption techniques will be readily understood by those skilled in the art and may include the use of various keys, passwords, codes, etc. as will also be readily understood by those skilled in the art. For example, U.S. Pat. Nos. 4,140,272; 5,337,357; 4,993,068 and 5,436,972 each disclose various approaches to encryption and the disclosures of these patents are incorporated herein in their entirety by reference.

The output of the sensor package 190 may be communicated to associated downstream decryption equipment via electrically conductive leads or pins, or may be inductively or optically coupled to associated equipment as will be readily understood by those skilled in the art. As would also be understood by those skilled in the art, electrical or other types of protection may be provided on the encrypted output portion to ensure that data, such as a database of fingerprints stored on the memory 193, is not readily readable by external connections and/or signal manipulations.

The sensor 30 and processor 192 may be configured to provide any of a range of integral sensor processing features. For example, the encrypted output may be a raw image, a processed image, fingerprint minutiae data, a yes/no match indication, or personal identification and digital signature keys as would be readily understood by those skilled in the art.

The illustrated sensor package 190 also includes a bead 196 of sealing material at the interface between the upper dielectric layer 52 of the sensor 30 and the adjacent portions of the housing 191. Other sealing arrangements are also contemplated by the present invention, for desirably providing a fluid tight seal at the interface between the exposed upper dielectric layer and the adjacent housing portions. In addition, a cleaning liquid may be used to routinely clean the window and reduce the contamination thereof. Since various alcohols, such as isopropyl alcohol are likely to be used as cleaning solutions, the housing 191 and sealing bead 196 are desirably resistant to such chemicals as would be readily understood by those skilled in the art.

Turning now additionally to FIG. 23 another sensor package 220 is illustrated, and the problems and solutions with respect to an integrated circuit package in accordance with the present invention are discussed. As would be readily understood by those skilled in the art, a fingerprint sensor integrated circuit presents a special packaging difficulty since it has to be touched by the finger being scanned.

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It is typically desired to avoid touching of an integrated circuit in conventional integrated circuit fabrication, in part, because of potential contamination. The main contaminants of concern are sodium and the other alkaline metals. These contaminants may cause mobile ions in the SiO₂ layers that are typically used to passivate the integrated circuit. The resulting oxide charge degrades device characteristics especially in MOS technology.

One conventional approach to controlling mobile ionic contamination uses hermetic packaging with a phosphorus-doped passivation layer over the integrated circuit. The phosphorus doping reduces contaminant mobility by trapping mechanisms as would be readily understood by those skilled in the art. Plastic packaging has now become more widespread, and a silicon nitride passivation layer may be used with the plastic packaging. Silicon nitride may greatly reduce the permeability to contaminants to permit direct contact between the finger of the user and the integrated circuit. Accordingly, silicon nitride may preferably be used as a passivation layer of the fingerprint sensor in accordance with the present invention.

A fingerprint sensor as in the present invention also raises several unique packaging requirements including: the package needs to be open to enable finger-to-sensor die contact; the package should be physically strong in order to withstand rough use; the package and die should be able to withstand repeated cleaning with detergent and/or disinfectant solutions, and including scrubbing; the die should be able to withstand contact with a wide variety of organic and inorganic contaminants, and should be able to withstand abrasion; and finally the package should be relatively inexpensive.

The illustrated package 220 of FIG. 23 addresses these packaging issues. The package 220 includes an integrated circuit die 221 mounted on a metal paddle 222 that is connected to the leadframe 223 during injection molding of the surrounding plastic material 191 of the package. Connections are made by bond wires 227 and the lead frame 223 to the outwardly extending leads 228 as would be readily understood by those skilled in the art. The upper surface of the plastic housing 191 includes an integrally molded opening 52 which permits contact to the die 221. The adhesion between the plastic molding compound and the adjacent upper surface portions of the die creates a seal in this illustrated embodiment. Accordingly, no separate sealing compound or manufacturing step may be needed as would be readily understood by those skilled in the art.

The integrated circuit die 221 may also include a passivation layer 224 of silicon nitride for reasons highlighted above. In addition, as shown in the illustrated sensor package 220, the die 221 may be provided with a second protective coating 225. Each of the coatings 224, 225 are desirably relatively thin, such as on the order of about a micrometer, in order to retain sensor sensitivity. The outer coating 225 may be an organic material, such as polyimide or PTFE (Teflon™) which yields advantages in wear resistance and physical protection. Inorganic coatings, such as silicon carbide or amorphous diamond, may also be used for the outer layer 225 and may greatly enhance wear resistance, especially to abrasive particles. In addition, the material of the protective die coating 225 is preferably compatible with standard IC pattern definition methods in order to enable bond pad etching, for example.

The bond pads on the integrated circuit die 221 may be provided by aluminum. Another perhaps more preferable approach seals the pads with a gold plug, as may be applied

by electroplating, as would be readily understood by those skilled in the art. As would also be readily understood by those skilled in the art, in order to reduce the height created by the looped bond wires 227, the die 221 may be directly flip-chip bonded in another embodiment of the invention, not shown. As would be readily understood by those skilled in the art, the sensor package 220 in other embodiments may be manufactured using tape automated bonding techniques.

Returning again briefly to FIG. 22, yet another aspect of the sensor package 190 is that the memory 198 and/or other integrated circuit components may be made to destruct or be rendered secure upon breach of the housing 191, for example. A coating 193 of material may be applied to the integrated circuit die(s) that causes destruction of the die if the coating is dissolved away as would be readily understood by those skilled in the art. The memory 193 may also self-destruct or empty its contents upon exposure to light or upon removal of a sustaining electrical current. Those of skill in the art will readily appreciate other approaches to ensuring the integrity of the data and processing capabilities of the sensor package 190 in accordance with the present invention. Accordingly, the present invention provides that sensitive data, such as a database of authorized fingerprints, encryption keys, or authorization codes, are not readily stolen from the sensor package 190. In addition, although the sensor package 190 may desirably incorporate the electrical field sensor 30 as described extensively herein, other sensors are also contemplated for inclusion with a secure sensor package in accordance with this aspect of the invention.

The various embodiments of the sensor 30 and its associated processing circuitry may implement any of a number of conventional fingerprint matching algorithms. For example, a suitable fingerprint matching algorithm and indexing approach for quick and efficient searching is described in copending patent application entitled "Methods and Related Apparatus for Fingerprint Indexing and Searching", having Ser. No. 08/589,064, assigned to the assignee of the present invention and the entire disclosure of which is incorporated herein by reference in its entirety.

As would be readily understood by those skilled in the art, fingerprint minutiae, that is, the branches or bifurcations and end points of the fingerprint ridges, are often used to determine a match between a sample print and a reference print database. Such minutiae matching may be readily implemented by the processing circuitry of the present invention as would be readily understood by those skilled in the art. For example, U.S. Pat. Nos. 3,859,633 and 3,893,080 both to Ho et al. are directed to fingerprint identification based upon fingerprint minutiae matching. U.S. Pat. No. 4,151,512 to Riganati et al., for further example, describes a fingerprint classification method using extracted ridge contour data. U.S. Pat. No. 4,185,270 to Fischer II et al. discloses a process for encoding and verification also based upon minutiae. In addition, U.S. Pat. No. 5,040,224 to Hara discloses an approach to preprocessing fingerprints to correctly determine a position of the core of each fingerprint image for later matching by minutiae patterns. The entire disclosures of each of these U.S. patents are incorporated herein by reference.

Turning now lastly to FIGS. 24-26 another significant aspect of the present invention is described. Because of the relatively fast and efficient processing of a fingerprint image provided by above identified sensor 30 and associated circuitry of the invention, the user may be provided with nearly real-time feedback regarding positioning of his finger on a fingerprint sensor, such as the illustrated electric field

sensor 30. Accordingly, the user may quickly and accurately reposition his finger, have his identification accurately determined, and promptly move forward with the intended task. In the past only a simple go or no-go indication has been described for a user as in U.S. Pat. No. 4,947,443 to Costello, for example, and with such an indication most likely taking a relatively long time. It is generally understood that unless such an indication can be given within several seconds, user frustration is likely to rise dramatically 10 with any further passage of time. Moreover, a simple go/no-go indication may only prompt the user to try again without any useful guidance on what may be causing the no-go indication.

The apparatus 200 (FIG. 24) illustratively includes a 15 fingerprint sensor 30 operatively connected to an image processor 201. Along the lines as discussed above, the image processor 201 may include the tapped delay line or other functional center point calculator 202 for determining a center point from the sensed fingerprint as will be readily appreciated by those skilled in the art. The location of the center point relative to a predetermined reference center point may be determined and an indication given the user via a position indicator 203. The image may also be further analyzed, and if the applied finger pressure is too great or too little, such an indication may also be given to the user. Accordingly, potential user frustration may be significantly reduced. A need to clean the sensor may also be effectively communicated to the user if repositioning and/or pressure changes are ineffective, such as after a predetermined 25 number of attempts.

Turning now more particularly to FIG. 25, a practical implementation of the position feedback sensing and indication is further described as applied in a computer workstation, such as the illustrated notebook computer 35 of the type including a keyboard 36 and display 37. Those of skill in the art will recognize the applicability of this aspect of the invention to many types of fixed and portable computer workstations in addition to the illustrated notebook computer.

In the illustrated embodiment, the fingerprint sensor 30 receives the finger of the user. The processor of the computer in cooperation with the fingerprint sensor 30 generates a display of the fingerprint image 206 along with its center point 205 on an image of a window 207 on the display 37. In the illustrated embodiment, the display also includes a target center point 208 to assist the user in repositioning his finger for an accurate reading.

In addition to the visual image indication, a further indication may be given by display of the words "move upward" and "move left" along with the illustrated associated directional arrows. An indication may also be given concerning a desired pressure, such as the illustrated words "increase pressure".

Yet another variation of the feedback and pressure indications may be in the form of synthetically generated speech messages issued from a speaker 39 mounted within the housing of the computer. For example, the generated voice messages illustratively include an annunciation to "move finger up and to the left" and "increase finger pressure". Other helpful messages are also contemplated by the present invention.

Still another embodiment of finger position feedback sensing and indication is understood with further reference to the apparatus 210 of FIG. 26. In this embodiment, the sensor 30 is used to operate an access controller 211 which, in turn, may operate a door, for example, to permit a

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properly identified user to enter. Simple visual indications in the form of LEDs 212, 213 for up and down motion, and left and right motion, respectively, may be provided to indicate to the user the proper positioning or repositioning of his finger. The illustrated embodiment also includes a plurality of LEDs 214 for indication of pressure. Those of skill in the art will readily appreciate many other variations and alternate embodiments of the feedback sensing and positioning in accordance with this aspect of the present invention.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A fingerprint sensor comprising:

an array of electric field sensing electrodes; a dielectric layer on a first surface of said array of electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto; and coherent drive means for applying a coherent electric field drive signal to said array of electric field sensing electrodes and adjacent portions of the finger so that said array of electric field sensing electrodes produce a fingerprint image output signal, said coherent drive means comprising a second dielectric layer on a second surface of said array of electric field sensing electrodes opposite the first surface, and a common drive electrode extending beneath at least a plurality of electric field sensing electrodes of said array of electric field sensing electrodes with the second dielectric layer therebetween so that the electric field drive signal radiates vertically between said common drive electrode and electric field sensing electrodes.

2. A fingerprint sensor according to claim 1 wherein said coherent drive means further comprises a drive circuit for powering said common drive electrode to generate the coherent electric field drive signal having a predetermined frequency.

3. A fingerprint sensor according to claim 1 further comprising a finger electrode positioned adjacent said dielectric layer for contact with the finger.

4. A fingerprint sensor according to claim 1 further comprising a respective shield electrode associated with each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes.

5. A fingerprint sensor according to claim 4 wherein each shield electrode comprises an electrically conductive layer surrounding a respective electric field sensing electrode with a dielectric layer therebetween.

6. A fingerprint sensor according to claim 4 further comprising active shield driving means for actively driving each of said shield electrodes.

7. A fingerprint sensor according to claim 6 wherein said active shield driving means comprises an amplifier operatively connected to each electric field sensing electrode and its associated shield electrode for actively driving the shield electrode with a portion of an output signal from said amplifier.

8. A fingerprint sensor according to claim 1 further comprising synchronous demodulator means operatively

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connected to said electric field sensing electrodes for synchronously demodulating signals therefrom.

9. A fingerprint sensor according to claim 1 further comprising dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

10. A fingerprint sensor according to claim 9 wherein said dynamic contrast enhancing means comprises:

a capacitor matrix operatively connected to said electric field sensing electrodes; and alternating current capacitor matrix drive means for driving said capacitor matrix.

11. A fingerprint sensor according to claim 10 wherein said alternating current capacitor matrix drive means comprises a synchronous demodulator.

12. A fingerprint sensor according to claim 9 wherein said dynamic contrast enhancing means comprises a resistor matrix operatively connected to said electric field sensing electrodes.

13. A fingerprint sensor according to claim 1 further comprising an amplifier operatively connected to each electric field sensing electrode.

14. A fingerprint sensor according to claim 1 further comprising multiplexing means for selectively reading each of said electric field sensing electrodes.

15. A fingerprint sensor according to claim 1 further comprising:

a substrate; and

an active semiconductor layer on said substrate comprising a plurality of semiconductor devices operatively connected to said electric field sensing electrodes.

16. A fingerprint sensor according to claim 15 further comprising package means for enclosing said substrate, said active semiconductor layer, said electric field sensing electrodes, and said dielectric layer; and wherein said package means has an opening therethrough in registry with said dielectric layer.

17. A fingerprint sensor comprising:

an array of electric field sensing electrodes; a dielectric layer on said electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto;

a respective shield electrode associated with each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent electric field sensing electrodes; and drive means for applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger, said drive means comprising a common drive electrode extending beneath at least a plurality of electric field sensing electrodes of said array of electric field sensing electrodes so that the electric field drive signal radiates vertically between said common drive electrode and electric field sensing electrodes for causing said electric field sensing electrodes to produce a fingerprint image output signal.

18. A fingerprint sensor according to claim 17 wherein each shield electrode comprises an electrically conductive layer surrounding a respective electric field sensing electrode with a dielectric layer therebetween.

19. A fingerprint sensor according to claim 17 further comprising active shield driving means for actively driving each of said shield electrodes.

20. A fingerprint sensor according to claim 19 wherein said active shield driving means comprises an amplifier

operatively connected to each electric field sensing electrode and its associated shield electrode for actively driving the shield electrode with a portion of an output signal from the amplifier.

21. A fingerprint sensor according to claim 17 wherein said drive means further comprises a drive circuit for powering said common drive electrode to generate the electric field drive signal having a predetermined frequency.

22. A fingerprint sensor according to claim 17 further comprising a finger electrode positioned adjacent said dielectric layer for contact with the finger.

23. A fingerprint sensor according to claim 17 further comprising synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom.

24. A fingerprint sensor according to claim 17 further comprising dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

25. A fingerprint sensor according to claim 24 wherein said dynamic contrast enhancing means comprises:

a capacitor matrix operatively connected to said electric field sensing electrodes; and

alternating current capacitor matrix drive means for driving said capacitor matrix.

26. A fingerprint sensor according to claim 25 wherein said alternating current capacitor matrix drive means comprises a synchronous demodulator.

27. A fingerprint sensor according to claim 24 wherein said dynamic contrast enhancing means comprises a resistor matrix operatively connected to said electric field sensing electrodes.

28. A fingerprint sensor according to claim 17 further comprising:

a substrate;

an active semiconductor layer on said substrate comprising a plurality of semiconductor devices operatively connected to said electric field sensing electrodes; and package means for enclosing said substrate, said active semiconductor layer, said electric field sensing electrodes, and said dielectric layer, and wherein said package means has an opening therethrough in registry with said dielectric layer.

29. A fingerprint sensor comprising:

an array of electric field sensing electrodes; a dielectric layer on said electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto;

a respective shield electrode comprising electrically conductive material surrounding each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent electric field sensing electrodes;

active shield driving means for actively driving each of said shield electrodes; and

drive means for applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger, said drive means comprising a common drive electrode extending beneath at least a plurality of electric field sensing electrodes of said array of electric field sensing electrodes so that the electric field drive signal radiates vertically between said common drive electrode and electric field sensing electrodes for causing said electric field sensing electrodes to produce a fingerprint image output signal.

30. A fingerprint sensor according to claim 29 wherein said active shield driving means comprises an amplifier operatively connected to each electric field sensing electrode and its associated shield electrode for actively driving the shield electrode with a portion of an output signal from the amplifier.

31. A fingerprint sensor according to claim 29 wherein said drive means further comprises a drive circuit for powering said common drive electrode to generate the electric field drive signal having a predetermined frequency.

32. A fingerprint sensor according to claim 29 further comprising a finger electrode positioned adjacent said dielectric layer for contact with the finger.

33. A fingerprint sensor according to claim 29 further comprising synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom.

34. A fingerprint sensor according to claim 29 further comprising dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

35. A fingerprint sensor according to claim 34 wherein said dynamic contrast enhancing means comprises:

a capacitor matrix operatively connected to said electric field sensing electrodes; and

alternating current capacitor matrix drive means for driving said capacitor matrix.

36. A fingerprint sensor according to claim 35 wherein said alternating current capacitor matrix drive means comprises a synchronous demodulator.

37. A fingerprint sensor according to claim 34 wherein said dynamic contrast enhancing means comprises a resistor matrix operatively connected to said electric field sensing electrodes.

38. A fingerprint sensor according to claim 29 further comprising:

a substrate;

an active semiconductor layer on said substrate comprising a plurality of semiconductor devices operatively connected to said electric field sensing electrodes and shield electrodes; and

package means for enclosing said substrate, said active semiconductor layer, said electric field sensing electrodes and shield electrodes, and said dielectric layer, and wherein said package means has an opening therethrough in registry with said dielectric layer.

39. A computer workstation comprising:

a housing;

a computer processor positioned within said housing; a display operatively connected to said computer processor;

a keyboard operatively connected to said computer processor; and

fingerprint sensor means operatively connected to said computer processor and mounted within said housing for protection thereby, said fingerprint sensor means comprising a finger sensing surface exposed through an opening in said housing;

said computer processor comprising access control means for permitting operation of the computer workstation only upon determining a match between a fingerprint sensed by said fingerprint sensor means and an authorized reference fingerprint;

said fingerprint sensor means comprising

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an array of electric field sensing electrodes, a dielectric layer on a first surface of said array of electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto, and drive means for applying an electric field drive signal to said array of electric field sensing electrodes and adjacent portions of the finger so that said array of electric field sensing electrodes produce a fingerprint image output signal, said drive means comprising a second dielectric layer on a second surface of said array of electric field sensing electrodes opposite the first surface, and a common drive electrode extending beneath at least a plurality of electric field sensing electrodes of said array of electric field sensing electrodes with the second dielectric layer therebetween so that the electric field drive signal radiates vertically between said common drive electrode and electric field sensing electrodes.

40. A computer workstation according to claim 39 wherein said drive means further comprises a coherent drive circuit for powering said common drive electrode to generate a coherent electric field drive signal having a predetermined frequency.

41. A computer workstation according to claim 39 further comprising a respective shield electrode associated with each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes.

42. A computer workstation according to claim 41 further comprising active shield driving means for actively driving each of said shield electrodes.

43. A computer workstation according to claim 39 further comprising synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom.

44. A computer workstation according to claim 39 further comprising dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

45. A method for sensing a fingerprint and generating a fingerprint image output signal, the method comprising the steps of:

providing an array of electric field sensing electrodes with a dielectric layer on a first surface of said array of electric field sensing electrodes for receiving a finger adjacent thereto, and further comprising a second dielectric layer on a second surface of said array of electric field sensing electrodes opposite the first surface, and a common drive electrode extending beneath at least a plurality of said array of electric field sensing electrodes with the second dielectric layer therebetween; and

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applying a coherent electric field drive signal to said array of electric field sensing electrodes and adjacent portions of the finger using the common drive electrode so that the electric field drive signal radiates vertically between the common drive electrode and electric field sensing electrodes to thereby cause said array of electric field sensing electrodes to produce a fingerprint image output signal.

46. A method according to claim 45 further comprising the step of shielding said electric field sensing electrodes by positioning a respective shield electrode surrounding each of said electric field sensing electrodes to shield each electric field sensing electrode from adjacent electric field sensing electrodes.

47. A method according to claim 46 further comprising the step of actively driving each of said shield electrodes with a portion of an output signal from an amplifier associated with each electric field sensing electrode.

48. A method according to claim 45 further comprising the step of synchronously demodulating signals from said electric field sensing electrodes.

49. A method according to claim 45 further comprising the step of dynamic enhancing contrast and uniformity of the fingerprint image output signal.

50. A method for sensing a fingerprint and generating a fingerprint image output signal, the method comprising the steps of:

providing an array of electric field sensing electrodes with a dielectric layer on said electric field sensing electrodes for receiving a finger adjacent thereto and a common drive electrode extending beneath at least a plurality of said array of electric field sensing electrodes;

applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger using the common drive electrode so that the electric field drive signal radiates vertically between the common drive electrode and electric field sensing electrodes to thereby cause said electric field sensing electrodes to produce a fingerprint image output signal; and shielding said electric field sensing electrodes by positioning a respective shield electrode surrounding each of said electric field sensing electrodes to shield each electric field sensing electrode from adjacent sensing electrodes.

51. A method according to claim 50 further comprising the step of actively driving each of said shield electrodes with a portion of an output signal from an amplifier associated with each electric field sensing electrode.

* * * * *

EXHIBIT E



US006259804B1

(12) **United States Patent**
Setlak et al.

(10) **Patent No.:** US 6,259,804 B1
(45) **Date of Patent:** *Jul. 10, 2001

(54) **FINGERPRINT SENSOR WITH GAIN CONTROL FEATURES AND ASSOCIATED METHODS**

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(73) Assignee: **Authentic, Inc.**, Melbourne, FL (US)

(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **08/858,142**

(22) Filed: **May 16, 1997**

(51) Int. Cl.⁷ **G06K 9/00**

(52) U.S. Cl. **382/124; 382/126**

(58) Field of Search 382/124, 125, 382/168, 172, 270, 274, 126, 282, 287; 341/110, 118, 126, 139, 155; 348/294

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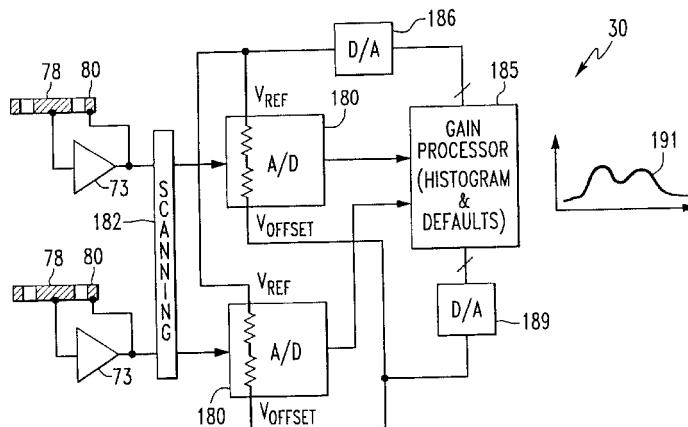
Primary Examiner—Phuoc Tran

(74) Attorney, Agent, or Firm—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

(57) **ABSTRACT**

A fingerprint sensor includes an array of fingerprint sensing elements; analog-to-digital (A/D) converters having a controllable range; a scanner to perform sequential A/D conversions of predetermined ones of the array of fingerprint sensing elements; and a range determining and setting circuit for controlling the range of the A/D converters based upon prior A/D conversions to thereby provide enhanced conversion resolution. A plurality of A/D converters are preferably used for simultaneously converting analog signals from a corresponding plurality of fingerprint sensing elements. The A/D converters may include at least one reference voltage input for permitting setting of first and second points of the range. The range scale determining and setting circuit may generate a histogram based upon prior A/D conversions. In addition, the range scale determining and setting circuit may set a default range for initial ones of the fingerprint sensing elements.

26 Claims, 6 Drawing Sheets



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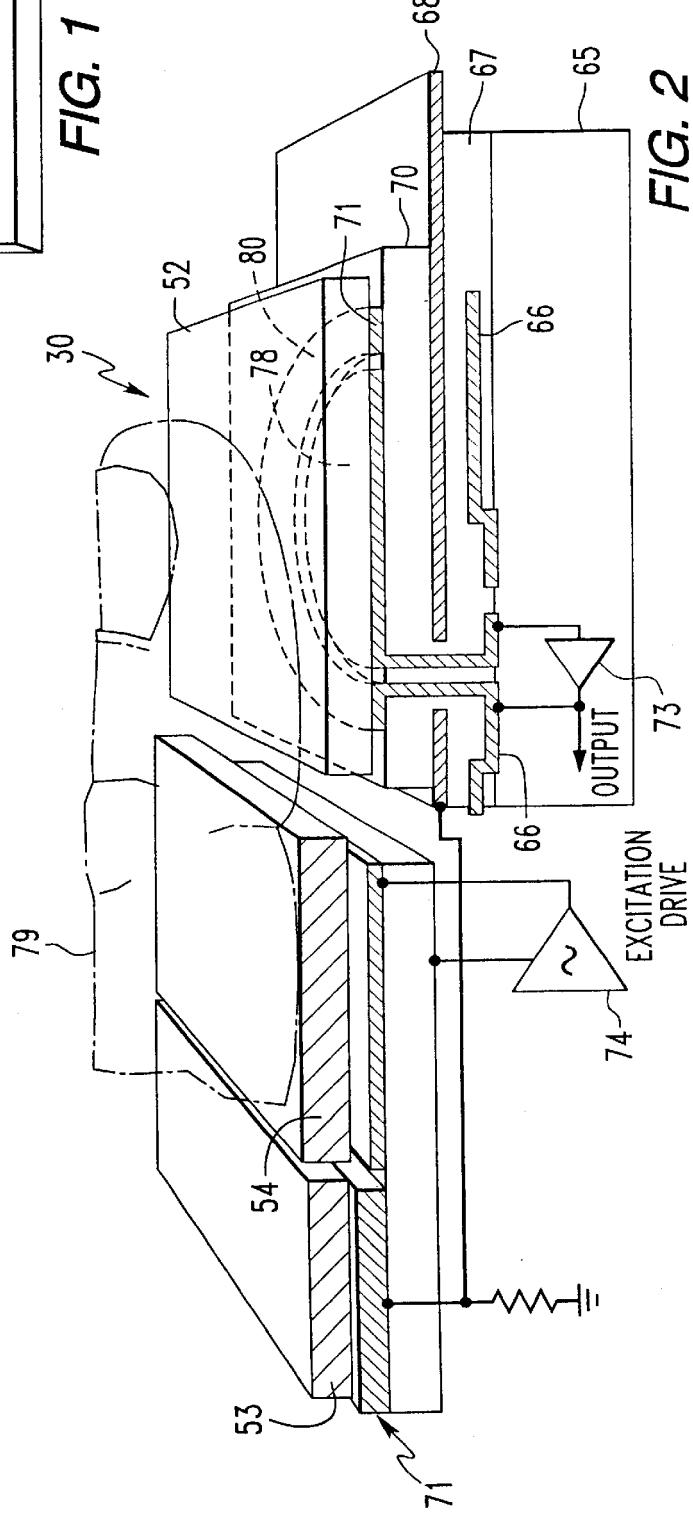
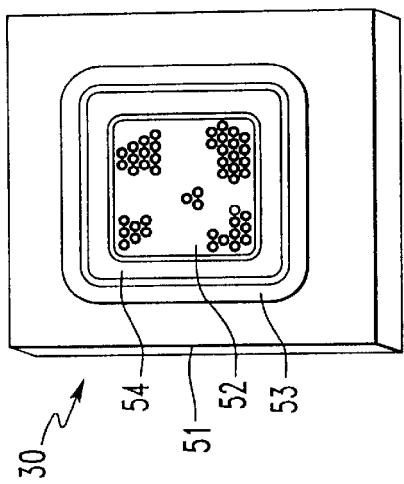
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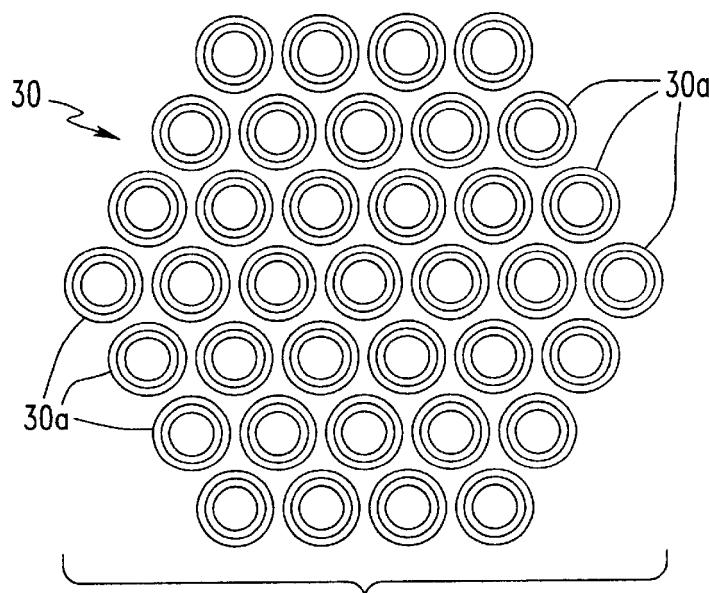
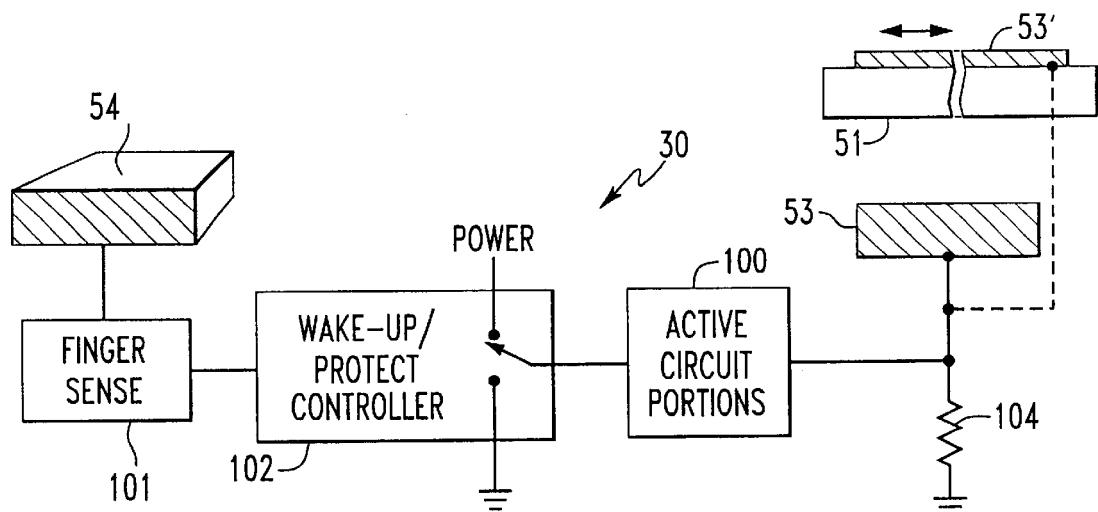


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**FIG.3****FIG.4**

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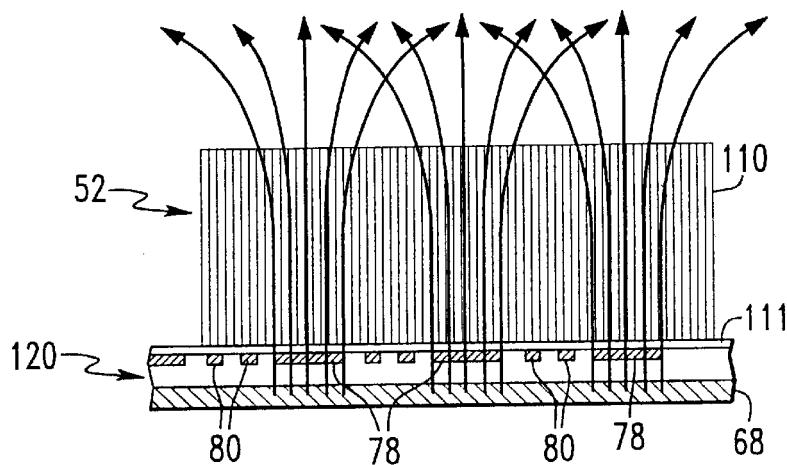


FIG. 5

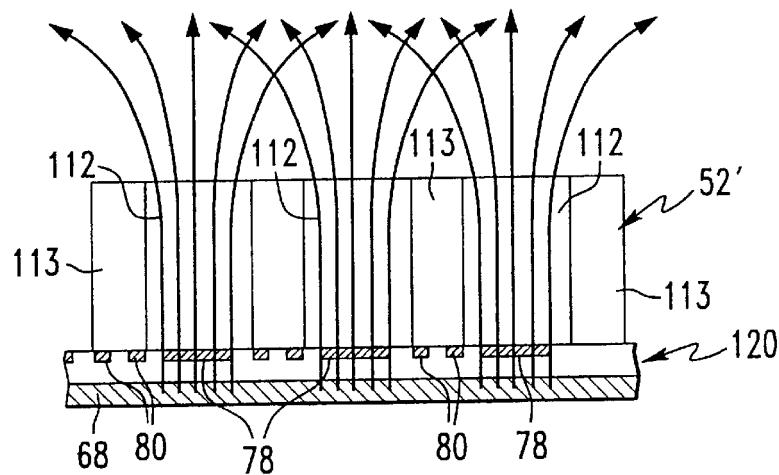


FIG. 6

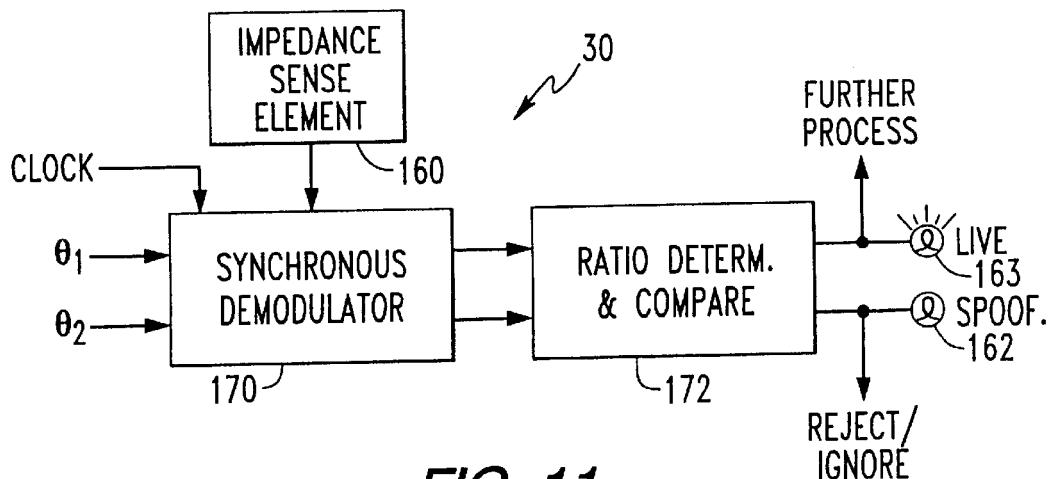


FIG. 11

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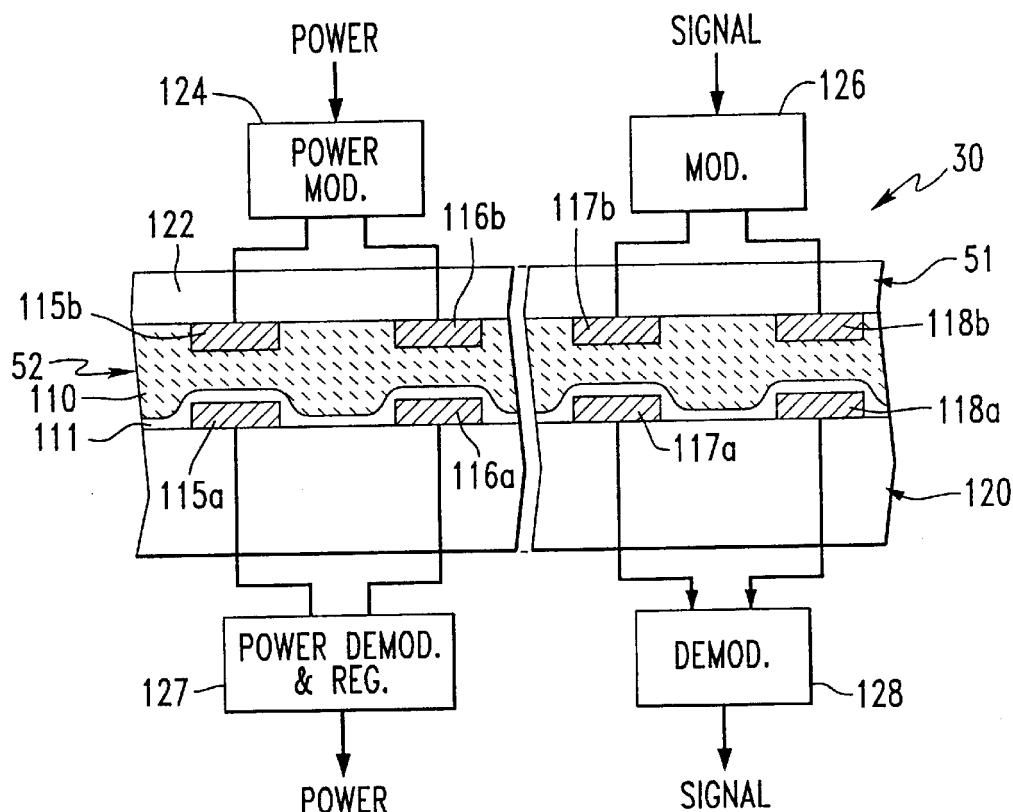


FIG. 7

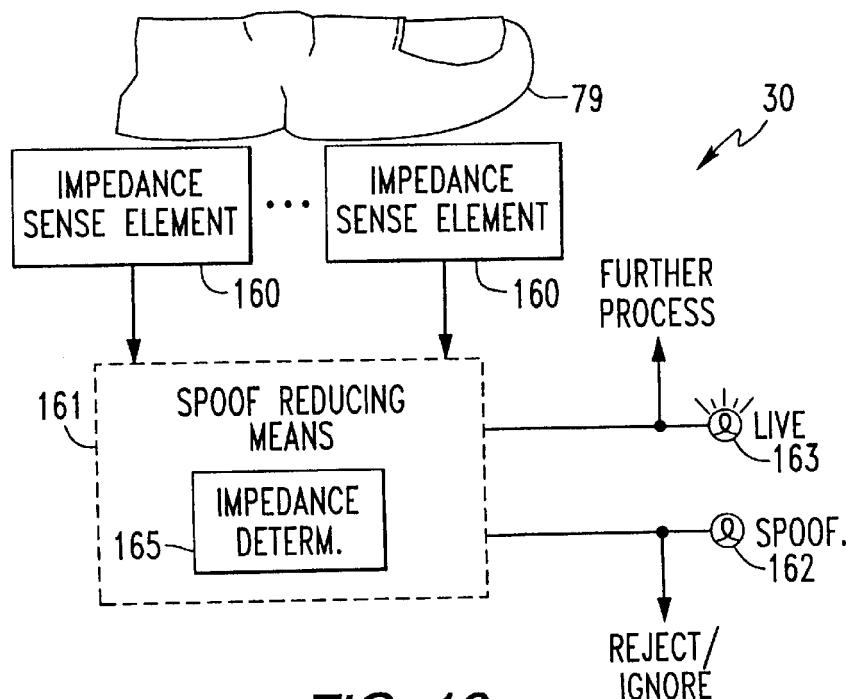


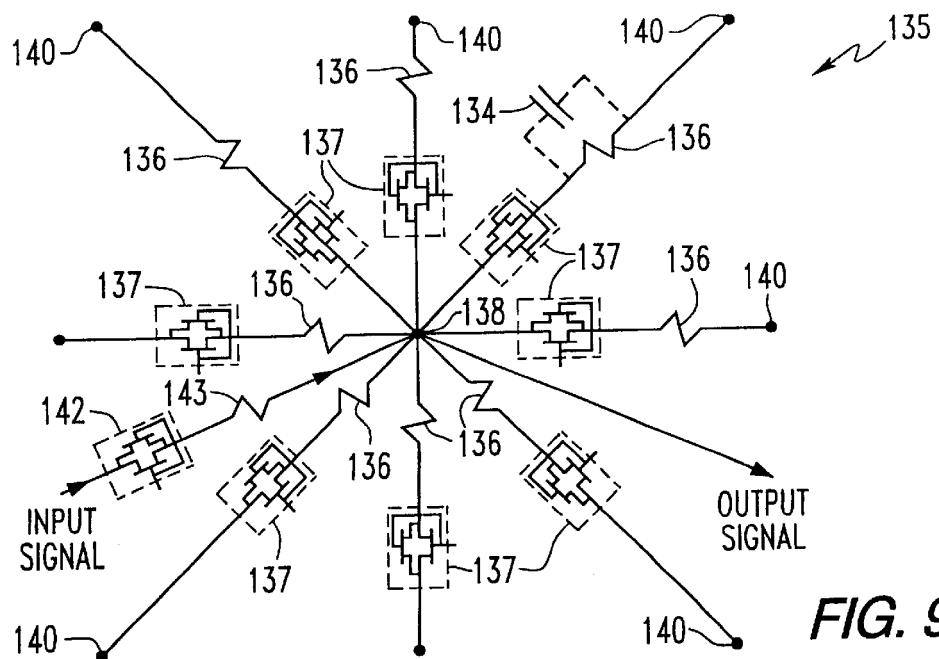
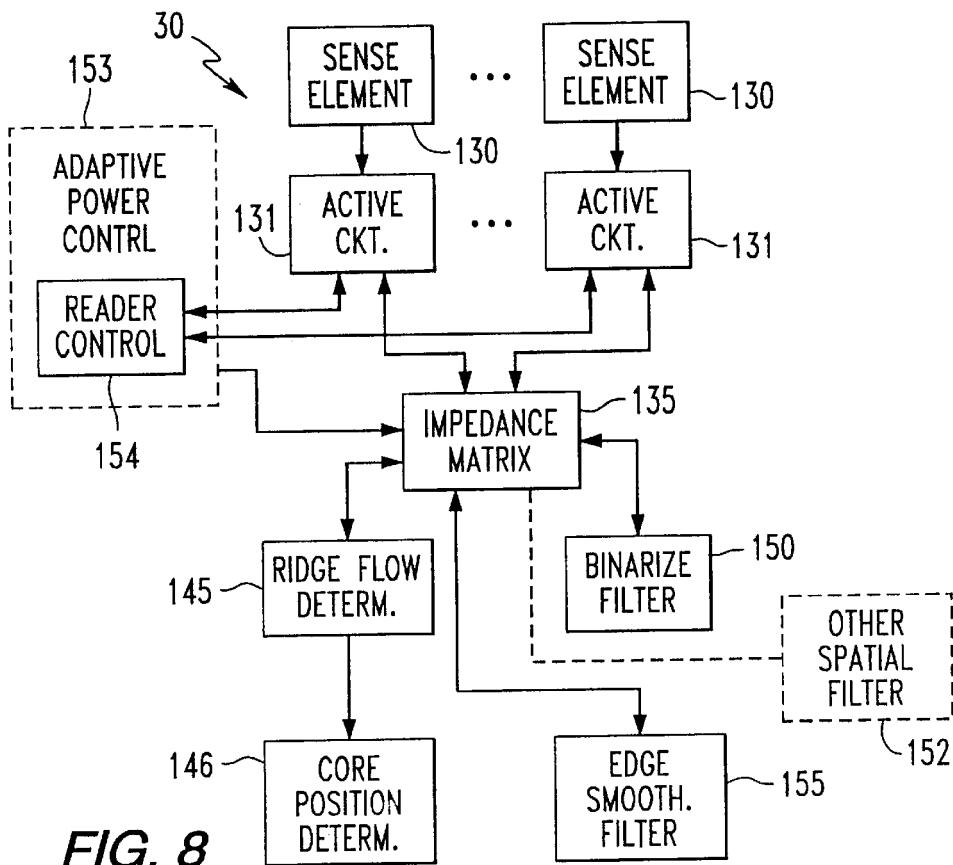
FIG. 10

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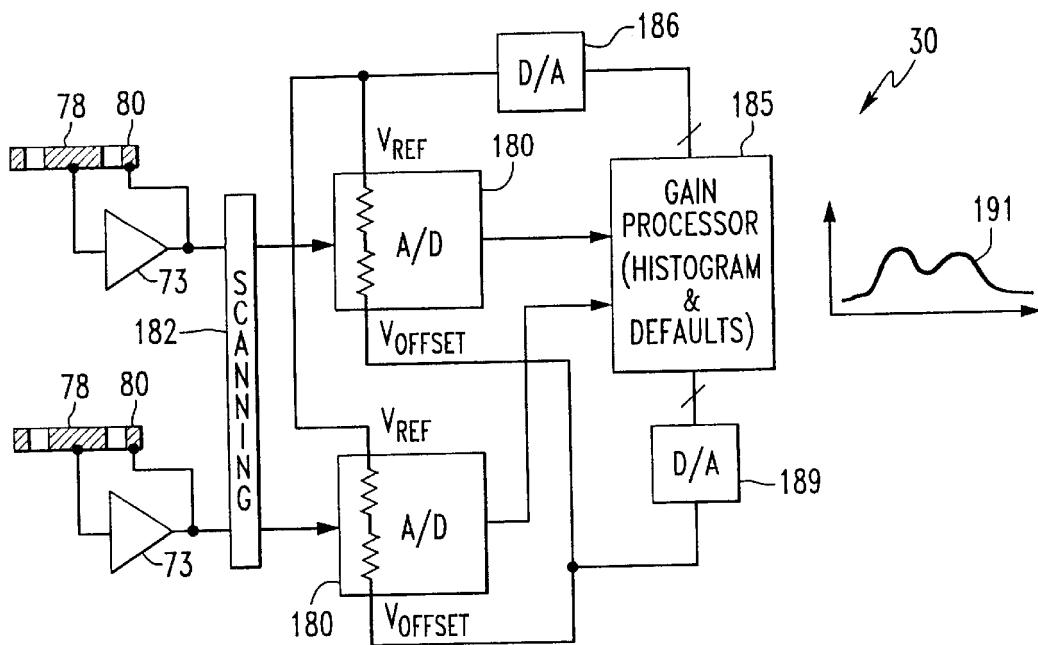


FIG. 12

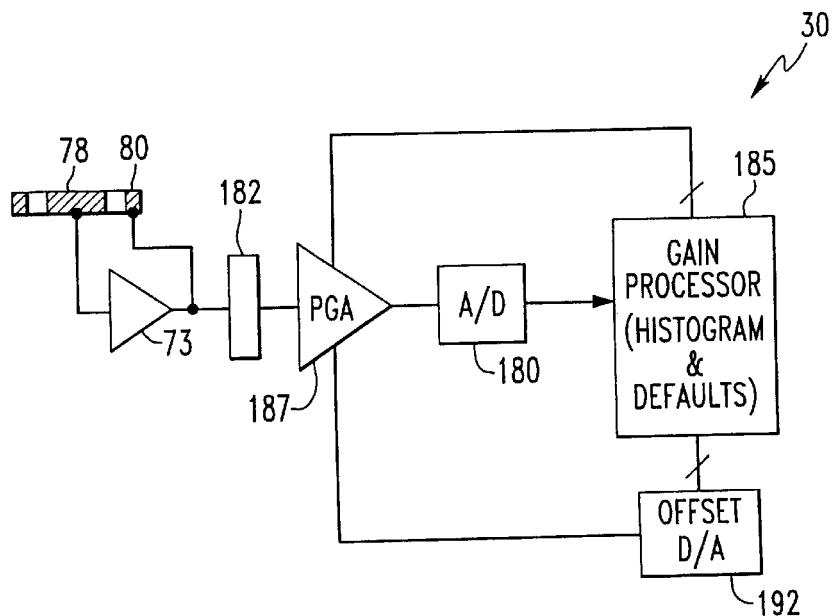


FIG. 13

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**FINGERPRINT SENSOR WITH GAIN
CONTROL FEATURES AND ASSOCIATED
METHODS**

FIELD OF THE INVENTION

The present invention relates to the field of personal identification and verification, and, more particularly, to the field of fingerprint sensing and processing.

BACKGROUND OF THE INVENTION

Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. In particular, a common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in a database to determine proper identification of a person, such as for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. For example, U.S. Pat. No. 4,210,899 to Swonger et al. discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. U.S. Pat. No. 4,525,859 to Bowles similarly discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. In addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams. Accordingly, optical sensors may thus be bulky and be susceptible to shock, vibration and surface contamination. Accordingly, an optical fingerprint sensor may be unreliable in service in addition to being bulky and relatively expensive due to optics and moving parts.

U.S. Pat. No. 4,353,056 to Tsikos discloses another approach to sensing a live fingerprint. In particular, the patent discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques. Unfortunately, the resilient materials required for the sensor may suffer from long term reliability problems. In addition, multiplexing techniques for driving and scanning each of the individual capacitors may be relatively slow and cumbersome. Moreover, noise and stray capacitances may adversely affect the plurality of relatively small and closely spaced capacitors.

U.S. Pat. No. 5,325,442 to Knapp discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing

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electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying portion of the finger surface which, in turn, is at ground potential. The sensor may be fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes. Further conductors may be provided on the surface of the dielectric material remote from the sensing electrodes and extending over regions between the sensing electrodes, for example, as lines or in grid form, which conductors are grounded in order to improve the electrical contact to the finger surface.

Unfortunately, driving the array of closely spaced sensing electrodes as disclosed in the Knapp et al. patent may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. Yet another difficulty with such a sensor, as with many optical sensors, is that different portions of the fingerprint may require relatively complicated post image collection processing to provide for usable signal levels and contrast to thereby permit accurate determination of the ridges and valleys of the fingerprint. For example, U.S. Pat. No. 4,811,414 to Fishbine et al. discloses methods for noise averaging, illumination equalizing, directional filtering, curvature correcting, and scale correcting for an optically generated fingerprint image. Unfortunately, the various processing steps are complex and require considerable computational power in a downstream processor. Signal processing of other fingerprint circuits may also be relatively complicated and therefore expensive and/or slow.

Greater advances in fingerprint sensing and matching for identification and verification are desirable for many applications. Unfortunately, current sensors and their associated circuitry may be too bulky, expensive and unreliable for a great many applications which would otherwise benefit from fingerprint identification and verification technology. In addition, fingerprint images generated by conventional sensors may vary considerably from individual-to-individual and for different sensing conditions. In addition, process variations in manufacturing may cause sensors to vary considerably from one to another. Accordingly, consistent results may be very difficult when using a conventional fingerprint sensor.

SUMMARY OF THE INVENTION

In view of the foregoing background, it is therefore an object of the present invention to provide a fingerprint sensor and related methods so that the fingerprint sensor may accommodate variations in image signal intensities, such as between different fingers, for different sensing conditions, or based on manufacturing process variations, for example.

This and other objects, features and advantages in accordance with the present invention are provided by a fingerprint sensor including an array of fingerprint sensing elements; analog-to-digital (A/D) conversion means having a controllable range; scanning means to perform sequential A/D conversions of predetermined ones of the array of fingerprint sensing elements; and range determining and setting means for controlling the range of the A/D conversion means based upon prior A/D conversions to thereby provide enhanced conversion resolution. The conversion

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resolution is enhanced despite variations in sensed fingers, conditions, or despite process variations resulting from manufacturing.

In one embodiment, the A/D conversion means preferably comprises a plurality or bank of A/D converters for simultaneously converting analog signals from a corresponding plurality of fingerprint sensing elements. By enabling dynamic exploitation of the full resolution range of the A/D converters, the accuracy of the sensing can be significantly improved.

The A/D conversion means may comprise at least one reference voltage input for permitting setting of the range. Accordingly, the range determining and setting means may comprise a processor, and at least one digital-to-analog converter connected between the processor and the at least one reference voltage input. In particular, the A/D converters may typically include a first reference voltage input and a second reference voltage input for setting corresponding first and second range points thereby defining the range. Alternately, or in addition thereto, the A/D conversion means may include at least one amplifier having a controllable gain for permitting setting of the range.

The range determining and setting means may comprise histogram generating means for generating a histogram based upon prior A/D conversions. In addition, the range determining and setting means may comprise default setting means for setting a default range for initial ones of the fingerprint sensing elements.

Each of the fingerprint sensing elements may be provided by an electric field sensing electrode and an amplifier associated therewith. A shield electrode may also be associated with each electric field sensing electrode and be connected to a respective amplifier.

A method aspect of the invention is for operating a fingerprint sensor of a type comprising an array of fingerprint sensing elements. The method preferably comprises the steps of: converting analog signals from the array of fingerprint sensing elements to digital signals using A/D converters having a controllable range; performing sequential A/D conversions of predetermined ones of the array of fingerprint sensing elements; and controlling the range of the A/D converters based upon prior A/D conversions to thereby provide enhanced conversion resolution.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top plan view of a fingerprint sensor in accordance with the present invention.

FIG. 2 is a schematic view of a circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 3 is a greatly enlarged top plan view of the sensing portion of the fingerprint sensor as shown in FIG. 1.

FIG. 4 is a schematic diagram of another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 5 is a greatly enlarged side cross-sectional view of a portion of the fingerprint sensor as shown in FIG. 1.

FIG. 6 is a greatly enlarged side cross-sectional view of a portion of an alternate embodiment of the fingerprint sensor in accordance with the invention.

FIG. 7 is a greatly enlarged side cross-sectional view of another portion of the fingerprint sensor as shown in FIG. 1.

FIG. 8 is a schematic block diagram of yet another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 9 is a schematic circuit diagram of a portion of the circuit as shown in FIG. 8.

FIG. 10 is a schematic block diagram of still another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 11 is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. 10.

FIG. 12 is a schematic block diagram of an additional circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 13 is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. 12.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. The scaling of various features, particularly layers in the drawing figures, have been exaggerated for clarity of explanation.

Referring to FIGS. 1-3, the fingerprint sensor 30 in accordance with the invention is initially described. The illustrated sensor 30 includes a housing or package 51, a dielectric layer 52 exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of output pins, not shown. A first conductive strip or external electrode 54 around the periphery of the dielectric layer 52, and a second external electrode 53 provide contact electrodes for the finger 79 as described in greater detail below. The sensor 30 may provide output signals in a range of sophistication levels depending on the level of processing incorporated in the package as would be readily understood by those skilled in the art.

The sensor 30 includes a plurality of individual pixels or sensing elements 30a arranged in array pattern as perhaps best shown in FIG. 3. As would be readily understood by those skilled in the art, these sensing elements are relatively small so as to be capable of sensing the ridges 59 and intervening valleys 60 of a typical fingerprint. As will also be readily appreciated by those skilled in the art, live fingerprint readings as from the electric field sensor 30 in accordance with the present invention may be more reliable than optical sensing, because the impedance of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate. In contrast, an optical sensor may be deceived by a photograph or other similar image of a fingerprint, for example.

The sensor 30 includes a substrate 65, and one or more active semiconductor devices formed thereon, such as the schematically illustrated amplifier 73. A first metal layer 66 interconnects the active semiconductor devices. A second or ground plane electrode layer 68 is above the first metal layer 66 and separated therefrom by an insulating layer 67. A third metal layer 71 is positioned over another dielectric layer 70. In the illustrated embodiment, the first external electrode 54 is connected to an excitation drive amplifier 74 which, in turn, drives the finger 79 with a signal may be typically in the range of about 1 KHz to 1 MHz. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor 30 may be relatively low, while the reliability is great.

An illustratively circularly shaped electric field sensing electrode 78 is on the insulating layer 70. The sensing

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electrode 78 may be connected to sensing integrated electronics, such as the illustrated amplifier 73 formed adjacent the substrate 65 as schematically illustrated, and as would be readily appreciated by those skilled in the art.

An annularly shaped shield electrode 80 surrounds the sensing electrode 78 in spaced relation therefrom. As would be readily appreciated by those skilled in the art, the sensing electrode 78 and its surrounding shield electrode 80 may have other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements 30a. The shield electrode 80 is an active shield which is driven by a portion of the output of the amplifier 73 to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electric field sensing electrodes 78.

The sensor 30 includes only three metal or electrically conductive layers 66, 68 and 71. The sensor 30 can be made without requiring additional metal layers which would otherwise increase the manufacturing cost, and, perhaps, reduce yields. Accordingly, the sensor 30 is less expensive and may be more rugged and reliable than a sensor including four or more metal layers as would be appreciated by those skilled in the art.

Another important aspect of the present invention is that the amplifier 73 may be operated at a gain of greater than about one to drive the shield electrode 80. Stability problems do not adversely affect the operation of the amplifier 73. Moreover, the common mode and general noise rejection are greatly enhanced according to this feature of the invention. In addition, the gain greater than one tends to focus the electric field with respect to the sensing electrode 78 as will be readily appreciated by those skilled in the art.

In general, the sensing elements 30a operate at very low currents and at very high impedances. For example, the output signal from each sensing electrode 78 is desirably about 5 to 10 millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element 30a, as defined by the outer dimensions of the shield electrode 80, may be about 0.002 to 0.005 inches in diameter. The ground plane electrode 68 protects the active electronic devices from unwanted excitation. The various signal feedthrough conductors for the electrodes 78, 80 to the active electronic circuitry may be readily formed as would be understood by those skilled in the art.

The overall contact or sensing surface for the sensor 30 may desirably be about 0.5 by 0.5 inches—a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor 30 in accordance with the invention is also fairly tolerant of dead pixels or sensing elements 30a. A typical sensor 30 includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor 30 may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

Turning now additionally to FIG. 4, another aspect of the sensor 30 of the invention is described. The sensor may include power control means for controlling operation of active circuit portions 100 based upon sensing finger contact with the first external electrode 54 as determined by the illustrated finger sense block or circuit 101. For example, the finger sense circuit 101 may operate based upon a change in impedance to an oscillator to thereby determine finger contact. Of course, other approaches for sensing contact

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with the finger are also contemplated by the invention. The power control means may include wake-up means for only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power. Alternately or additionally, the power control means may further comprise protection means for grounding active circuit portions upon not sensing finger contact with the first external electrode. In the illustrated embodiment, a combination of wake-up and protection controller circuits 101 are illustrated.

Moreover, the fingerprint sensor 30 may further comprise finger charge bleed means for bleeding a charge from a finger or other object upon contact therewith. The finger charge bleed means may be provided by the second external electrode 53 carried by the package 51 for contact by a finger, and a charge bleed resistor 104 connected between the second external electrode and an earth ground. As schematically illustrated in the upper right hand portion of FIG. 4, the second electrode may alternately be provided by a movable electrically conductive cover 53' slidably connected to the package 51 for covering the opening to the exposed upper dielectric layer 52. A pivotally connected cover is also contemplated by the present invention. Accordingly, under normal conditions, the charge would be bled from the finger as the cover 53' is moved to expose the sensing portion of the sensor 30.

In addition, the finger charge bleed means and power control means may be such that the active portions remain grounded until the charge bleed means can remove the charge on the finger before powering the active circuit portions, such as by providing a brief delay during wake-up sufficient to permit the charge to be discharged through the resistor 104 as would be readily understood by those skilled in the art. Accordingly, power may be conserved in the sensor 30 and ESD protection provided by the sensor so that the sensor is relatively inexpensive, yet robust and conserves power.

Referring now additionally to FIG. 5 yet another significant feature of the sensor 30 is described. The dielectric covering 52 may preferably comprise a z-axis anisotropic dielectric layer 110 for focussing an electric field, shown by the illustrated field lines, at each of the electric field sensing electrodes 78. In other words, the dielectric layer 110 may be relatively thick, but not result in defocussing of the electric fields propagating therethrough because of the z-axis anisotropy of the material. Typically there would be a trade-off between field focus and mechanical protection. Unfortunately, a thin film which is desirable for focussing may permit the underlying circuit to be more easily subject to damage.

The z-axis anisotropic dielectric layer 110 of the present invention, for example, may have a thickness in range of about 0.0001 to 0.004 inches. Of course, the z-axis anisotropic dielectric layer 110 is also preferably chemically resistant and mechanically strong to withstand contact with fingers, and to permit periodic cleanings with solvents. The z-axis anisotropic dielectric layer 110 may preferably define an outermost protective surface for the integrated circuit die 120. Accordingly, the overall dielectric covering 52 may further include at least one relatively thin oxide, nitride, carbide, or diamond layer 111 on the integrated circuit die 120 and beneath the z-axis anisotropic dielectric layer 110. The thin layer 111 will typically be relatively hard, and the z-axis anisotropic dielectric layer 110 is desirably softer to thereby absorb more mechanical activity.

The z-axis anisotropic dielectric layer 110 may be provided by a plurality of oriented dielectric particles in a cured

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matrix. For example, the z-axis anisotropic dielectric layer 110 may comprise barium titanate in a polyimide matrix. Those of skill in the art will appreciate other materials exhibiting z-axis anisotropy suitable for the present invention. For example, certain ceramics exhibit dielectric anisotropy as would also be appreciated by those skilled in the art.

Turning to FIG. 6, another variation of a z-axis dielectric covering 52' is schematically shown by a plurality of high dielectric portions 112 aligned with corresponding electric field sensing electrodes 78, and a surrounding matrix of lower dielectric portions 113. This embodiment of the dielectric covering 52' may be formed in a number of ways, such as by forming a layer of either the high dielectric or low dielectric portions, selectively etching same, and filling the openings with the opposite material. Another approach may be to use polarizable microcapsules and subjecting same to an electric field during curing of a matrix material. A material may be compressed to cause the z-axis anisotropy. Laser and other selective processing techniques may also be used as would be readily understood by those skilled in the art.

Another aspect of the invention relates to being able to completely cover and protect the entire upper surface of the integrated circuit die 120, and still permit connection and communication with the external devices and circuits as now further explained with reference to FIG. 7. The third metal layer 71 (FIG. 2) preferably further includes a plurality of capacitive coupling pads 116a-118a for permitting capacitive coupling of the integrated circuit die 120. Accordingly, the dielectric covering 52 is preferably continuous over the capacitive coupling pads 116a-118a and the array of electric field sensing electrodes 78 of the pixels 30a (FIG. 1). In sharp contrast to this feature of the present invention, it is conventional to create openings through an outer coating to electrically connect to the bond pads. Unfortunately, these openings would provide pathways for water and/or other contaminants to come in contact with and damage the die.

A portion of the package 51 includes a printed circuit board 122 which carries corresponding pads 115b-118b. A power modulation circuit 124 is coupled to pads 115b-116b, while a signal modulation circuit 126 is illustrative coupled to pads 117b-118b. As would be readily understood by those skilled in the art, both power and signals may be readily coupled between the printed circuit board 122 and the integrated circuit die 120, further using the illustrated power demodulation/regulator circuit 127, and the signal demodulation circuit 128. The z-axis anisotropic dielectric layer 110 also advantageously reduces cross-talk between adjacent capacitive coupling pads. This embodiment of the invention 30 presents no penetrations through the dielectric covering 52 for moisture to enter and damage the integrated circuit die 120. In addition, another level of insulation is provided between the integrated circuit and the external environment.

For the illustrated fingerprint sensor 30, the package 51 preferably has an opening aligned with the array of electric field sensing electrodes 78 (FIGS. 1-3). The capacitive coupling and z-axis anisotropic layer 110 may be advantageously used in a number of applications in addition to the illustrated fingerprint sensor 30, and particularly where it is desired to have a continuous film covering the upper surface of the integrated circuit die 120 and pads 116a-118a.

Further aspects of the manufacturing of the sensor 30 including the z-axis anisotropic dielectric material are explained in U.S. patent application, Ser. No. 08/857,525, filed May 16, 1997, entitled "Direct Chip Attachment Method and Devices Produced Thereby". This patent appli-

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cation has attorney work docket no. 18763, is assigned to the present assignee, and the entire disclosure of which is incorporated herein by reference.

Referring additionally to FIGS. 8 and 9, impedance matrix filtering aspects of the invention are now described. As shown in FIG. 8, the fingerprint sensor 30 may be considered as comprising an array of fingerprint sensing elements 130 and associated active circuits 131 for generating signals relating to the fingerprint image. The illustrated sensor 30 also includes an impedance matrix 135 connected to the active circuits for filtering the signals therefrom.

As shown with more particular reference to FIG. 9, the impedance matrix 135 includes a plurality of impedance elements 136 with a respective impedance element connectable between each active circuit of a respective fingerprint sensing element as indicated by the central node 138, and the other active circuits (outer nodes 140). The impedance matrix 135 also includes a plurality of switches 137 with a respective switch connected in series with each impedance element 136. An input signal may be supplied to the central node 138 via the illustrated switch 142 and its associated impedance element 143. The impedance element may one or more of a resistor as illustrated, and a capacitor 134 as would be readily appreciated by those skilled in the art.

Filter control means may operate the switches 137 to perform processing of the signals generated by the active circuits 131. In one embodiment, the fingerprint sensing elements 130 may be electric field sensing electrodes 78, and the active circuits 131 may be amplifiers 73 (FIG. 2). Of course other sensing elements and active circuits may also benefit from the impedance matrix filtering of the present invention as would be readily understood by those skilled in the art.

Ridge flow determining means 145 may be provided for selectively operating the switches 137 of the matrix 135 to determine ridge flow directions of the fingerprint image. More particularly, the ridge flow determining means 145 may selectively operate the switches 137 for determining signal strength vectors relating to ridge flow directions of the fingerprint image. As would be readily understood by those skilled in the art, the ridge flow directions may be determined based upon well known rotating slit principles.

The sensor 30 may include core location determining means 146 cooperating with the ridge flow determining means 145 for determining a core location of the fingerprint image. The position of the core is helpful, for example, in extracting and processing minutiae from the fingerprint image as would also be readily understood by those skilled in the art.

As also schematically illustrated in FIG. 8, a binarizing filter 150 may be provided for selectively operating the switches 137 to convert a gray scale fingerprint image to a binarized fingerprint image. Considered another way, the impedance matrix 135 may be used to provide dynamic image contrast enhancement. In addition, an edge smoothing filter 155 may be readily implemented to improve the image. As also schematically illustrated other spatial filters 152 may also be implemented using the impedance matrix 135 for selectively operating the switches 137 to spatially filter the fingerprint image as would be readily appreciated by those of skill in the art. Accordingly, processing of the fingerprint image may be carried out at the sensor 30 and thereby reduce additional downstream computational requirements.

As shown in the illustrated embodiment of FIG. 9, the impedance matrix 135 may comprise a plurality of impedance elements with a respective impedance element 136

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connectable between each active circuit for a given finger-
print sensing element **130** and eight other active circuits for
respective adjacent fingerprint sensing elements.

Yet another aspect of the invention is the provision of
control means **153** for sequentially powering sets of active
circuits **131** to thereby conserve power. Of course, the
respective impedance elements **136** are desirably also
sequentially connected to perform the filtering function. The
powered active circuits **131** may be considered as defining
a cloud or kernel as would be readily appreciated by those
skilled in the art. The power control means **153** may be
operated in an adaptive fashion whereby the size of the area
used for filtering is dynamically changed for preferred image
characteristics as would also be readily understood by those
skilled in the art. In addition, the power control means **153**
may also power only certain ones of the active circuits
corresponding to a predetermined area of the array of
sensing elements **130**. For example, every other active
circuit **131** could be powered to thereby provide a larger
area, but reduced power consumption as would also be
understood by those skilled in the art.

Reader control means **154** may be provided to read only
predetermined subsets of each set of active circuits **131** so
that a contribution from adjacent active circuits is used for
filtering. In other words, only a subset of active circuits **131**
are typically simultaneously read although adjacent active
circuits **131** and associated impedance elements **136** are also
powered and connected, respectively. For example, 16
impedance elements **136** could define a subset and be readily
simultaneously read. The subset size could be optimized for
different sized features to be determined as would be readily
appreciated by those skilled in the art.

Accordingly, the array of sense elements **130** can be
quickly read, and power consumption substantially reduced
since all of the active circuits **131** need not be powered for
reading a given set of active circuits. For a typical sensor, the
combination of the power control and impedance matrix
features described herein may permit power savings by a
factor of about 10 as compared to powering the full array.

It is another important advantage of the fingerprint sensor
30 according to present invention to guard against spoofing
or deception of the sensor into incorrectly treating a simu-
lated image as a live fingerprint image. For example, optical
sensors may be deceived or spoofed by using a paper with
a fingerprint image thereon. The unique electric field sensing
of the fingerprint sensor **30** of the present invention provides
an effective approach to avoiding spoofing based upon the
complex impedance of a finger.

As shown in FIG. 10, the fingerprint sensor **30** may be
considered as including an array of impedance sensing
elements **160** for generating signals related to a finger **79** or
other object positioned adjacent thereto. In the embodiment
described herein, the impedance sensing elements **160** are
provided by electric field sensing electrodes **78** and amplifiers
73 (FIG. 2) associated therewith. In addition, a guard
shield **80** may be associated with each electric field sensing
electrode **78** and connected to a respective amplifier **73**.
Spoof reducing means **161** is provided for determining
whether or not an impedance of the object positioned
adjacent the array of impedance sensing elements **160**
corresponds to a live finger **79** to thereby reduce spoofing of
the fingerprint sensor by an object other than a live finger. A
spoofing may be indicated, such as by the schematically
illustrated lamp **163** and/or used to block further processing.
Alternately, a live fingerprint determination may also be
indicated by a lamp **164** and/or used to permit further

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processing of the fingerprint image as will be readily appre-
ciated by those skilled in the art. Many other options for
indicating a live fingerprint or an attempted spoofing will be
readily appreciated by those skilled in the art.

In one embodiment, the spoof reducing means **161** may
include impedance determining means **165** to detect a com-
plex impedance having a phase angle in a range of about 10
to 60 degrees corresponding to a live finger **79**. Alternately,
the spoof reducing means **161** may detect an impedance
having a phase angle of about 0 degrees corresponding to
some objects other than a live finger, such as a sheet of paper
having an image thereon, for example. In addition, the spoof
reducing means **161** may detect an impedance of 90 degrees
corresponding to other objects.

Turning now to FIG. 11, another embodiment of spoof
reducing means is explained. The fingerprint sensor **30** may
preferably includes drive means for driving the array of
impedance sensing elements **160**, such as the illustrated
excitation amplifier **74** (FIG. 2). The sensor also includes
synchronous demodulator means **170** for synchronously
demodulating signals from the array of impedance sensing
elements **160**. Accordingly, in one particularly advantageous
embodiment of the invention, the spoof reducing means
comprises means for operating the synchronous demodula-
tor means **170** at at least one predetermined phase rotation
angle. For example, the synchronous demodulator means
170 could be operated in a range of about 10 to 60 degrees,
and the magnitude compared to a predetermined threshold
indicative of a live fingerprint. A live fingerprint typically
has a complex impedance within the range of 10 to 60
degrees.

Alternately, ratio generating and comparing means **172**
may be provided for cooperating with the synchronous
demodulator means **170** for synchronously demodulating
signals at first and second phase angles θ_1 , θ_2 , generating an
amplitude ratio thereof, and comparing the amplitude ratio
to a predetermined threshold to determine whether the object
is a live fingerprint or other object. Accordingly, the syn-
chronous demodulator **170** may be readily used to generate
the impedance information desired for reducing spoofing of
the sensor **30** by an object other than a live finger. The first
angle θ_1 and the second θ_2 may have a difference in a range
of about 45 to 90 degrees, for example. Other angles are also
contemplated by the invention as would be readily appre-
ciated by those skilled in the art.

The fingerprint sensor **30** also includes an automatic gain
control feature to account for a difference in intensity of the
image signals generated by different fingers or under differ-
ent conditions, and also to account for differences in sensor
caused by process variations. It is important for accurately
producing a fingerprint image, that the sensor can discrimi-
nate between the ridges and valleys of the fingerprint.
Accordingly, the sensor **30** includes a gain control feature, a
first embodiment of which is understood with reference to
FIG. 12.

As shown in FIG. 12, the illustrated portion of the
fingerprint sensor **30** includes an array of fingerprint sensing
elements in the form of the electric field sensing electrodes
78 and surrounding shield electrodes **80** connected to the
amplifiers **73**. Other fingerprint sensing elements may also
benefit from the following automatic gain control imple-
mentations as will be appreciated by those skilled in the art.

The signal processing circuitry of the sensor **30** preferably
includes a plurality of analog-to-digital (A/D) converters
180 as illustrated. Moreover, each of these A/D converters
180 may have a controllable scale. Scanning means **182**

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sequentially connects different elements to the bank of A/D converters **180**. The illustrated gain processor **185** provides range determining and setting means for controlling the range of the A/D converters **180** based upon prior A/D conversions to thereby provide enhanced conversion resolution. The A/D converters **180** may comprise the illustrated reference voltage input V_{ref} and offset voltage input V_{offset} for permitting setting of the range as would be readily appreciated by those skilled in the art. Accordingly, the range determining and setting means may also comprise a first digital-to-analog D/A converter **186** connected between the gain processor **185** and the reference voltage V_{ref} inputs of the A/D converters **180** as would also be readily understood by those skilled in the art. In addition, a second D/A converter **189** is also illustratively connected to the offset voltage inputs V_{offset} from the gain processor **185**.

The gain processor **185** may comprise histogram generating means for generating a histogram, as described above, and based upon prior A/D conversions. The graph adjacent the gain processor **185** in FIG. 12 illustrates a typical histogram plot **191**. The histogram plot **191** includes two peaks corresponding to the sensed ridges and valleys of the fingerprint as would be readily appreciated by those skilled in the art. By setting the range for the A/D converters **180**, the peaks can be readily positioned as desired to thereby account for the variations discussed above and use the full resolution of the A/D converters **180**.

Turning additionally to FIG. 13, the A/D converters **180** may include an associated input amplifier for permitting setting of the range. In this variation, the range determining and setting means may also comprise the illustrated gain processor **185**, and wherein the amplifier is a programmable gain amplifier (PGA) **187** connected to the processor. A digital word output from the gain processor **185** sets the gain of the PGA **187** so that full use of the resolution of the A/D converters **180** is obtained for best accuracy. A second digital word output from the gain processor **185** and coupled to the amplifier **187** through the illustrated D/A converter **192** may also control the offset of the amplifier as would also be readily appreciated by those skilled in the art.

The range determining and setting means of the gain processor **185** may comprise default setting means for setting a default range for initial ones of the fingerprint sensing elements. The automatic gain control feature of the present invention allows the D/A converters **180** to operate over their full resolution range to thereby increase the accuracy of the image signal processing.

Other aspects, advantages, and features relating to sensing of fingerprints are disclosed in copending U.S. patent application Ser. No. 08/592,469 entitled "Electric Field Fingerprint Sensor and Related Methods", and U.S. patent application Ser. No. 08/671,430 entitled "Integrated Circuit Device Having an Opening Exposing the Integrated Circuit Die and Related Methods", both assigned to the assignee of the present invention, and the entire disclosures of which are incorporated herein by reference. In addition, many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A fingerprint sensor to enhance conversion resolution of ridges and valleys of sensed fingerprints, the fingerprint sensor comprising:

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an array of fingerprint sensing elements, each element comprising an electric field sensing electrode and an amplifier associated therewith;

analog-to-digital (A/D) conversion means having a controllable range and for converting analog signals from said array of fingerprint sensing elements to digital signals based upon the range;

scanning means responsive to said array of fingerprint sensing elements and positioned in communication with said A/D conversion means for operating said A/D conversion means and said array of fingerprint sensing elements to perform sequential A/D conversions of predetermined ones of said array of fingerprint sensing elements; and

range determining and setting means responsive to each said A/D conversion means for controlling the range of said A/D conversion means based upon a plurality of the sequential A/D conversions performed by said A/D conversion means to thereby provide enhanced conversion resolution of ridges and valleys of sensed fingerprints.

2. A fingerprint sensor according to claim 1 wherein said A/D conversion means comprises a plurality of A/D converters for simultaneously converting analog signals from a corresponding plurality of fingerprint sensing elements.

3. A fingerprint sensor according to claim 1 wherein said A/D conversion means comprises at least one range input for permitting setting of at least one range point; and wherein said range determining and setting means comprises a processor, and at least one digital-to-analog converter connected between said processor and said at least one range input.

4. A fingerprint sensor according to claim 1 wherein said A/D conversion means comprises a first reference voltage input for permitting setting of a first range point.

5. A fingerprint sensor according to claim 4 wherein said A/D conversion means further comprises a second reference voltage input for permitting setting of a second range point.

6. A fingerprint sensor according to claim 1 wherein said A/D conversion means comprises at least one amplifier for permitting setting of the range.

7. A fingerprint sensor according to claim 1 wherein said range determining and setting means comprises histogram generating means for generating a histogram based upon the plurality of sequential A/D conversions.

8. A fingerprint sensor according to claim 1 wherein said range determining and setting means comprises default setting means for setting a default range for initial ones of said fingerprint sensing elements.

9. A fingerprint sensor according to claim 1 further comprising a shield electrode associated with each electric field sensing electrode and connected to a respective amplifier.

10. A fingerprint sensor to enhance conversion resolution of ridges and valleys of sensed fingerprints, the fingerprint sensor comprising:

an array of fingerprint sensing elements, each element comprising an electric field sensing electrode and an amplifier associated therewith;

at least one analog-to-digital (A/D) converter having at least one reference voltage input and for converting an analog signal from at least one fingerprint sensing element to a digital signal based upon the at least one reference voltage;

scanning means responsive to said array of fingerprint sensing elements and positioned in communication

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with said at least one A/D converter for operating said at least one A/D converter and said array of fingerprint sensing elements to perform sequential A/D conversions of predetermined ones of said array of fingerprint sensing elements; and

reference voltage determining and setting means responsive to said at least one A/D converter for controlling the at least one reference voltage of said at least one A/D converter based upon a plurality of the sequential A/D conversions performed by said A/D conversion means to thereby provide enhanced conversion resolution of ridges and valleys of sensed fingerprints.

11. A fingerprint sensor according to claim **10** wherein said at least one A/D converter comprises a plurality of A/D converters for simultaneously converting analog signals from a corresponding plurality of fingerprint sensing elements.

12. A fingerprint sensor according to claim **10** wherein said reference voltage determining and setting means comprises a processor, and at least one digital-to-analog converter connected between said processor and said at least one reference voltage input.

13. A fingerprint sensor according to claim **10** further comprising at least one amplifier cooperating with said at least one A/D converter for permitting setting of the range thereof.

14. A fingerprint sensor according to claim **10** wherein said reference voltage determining and setting means comprises histogram generating means for generating a histogram based upon the plurality of sequential A/D conversions.

15. A fingerprint sensor according to claim **10** wherein said reference voltage determining and setting means comprises default setting means for setting at least one default reference voltage for initial ones of said fingerprint sensing elements.

16. A fingerprint sensor according to claim **10** further comprising a shield electrode associated with each electric field sensing electrode and connected to a respective amplifier.

17. A fingerprint sensor to enhance conversion resolution of ridges and valleys of sensed fingerprints, the fingerprint sensor comprising:

an array of fingerprint sensing elements, each element comprising an electric field sensing electrode and an amplifier associated therewith;

a plurality of analog-to-digital (A/D) converters each having at least one reference voltage input and for converting an analog signal from at least one fingerprint sensing element to a digital signal based upon the at least one reference voltage;

scanning means responsive to said array of fingerprint sensing elements and in communication with said plurality of A/D converters for operating said plurality of A/D converters and said array of fingerprint sensing elements to perform sequential A/D conversions of predetermined ones of said array of fingerprint sensing elements; and

reference voltage determining and setting means responsive to said plurality of A/D converters for controlling the at least one reference voltage of each of said

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plurality of A/D converters based upon a plurality of the sequential A/D conversions performed by said plurality of A/D converters to thereby provide enhanced conversion resolution of ridges and valleys of sensed fingerprints, said reference voltage determining and setting means comprising histogram generating means for generating a histogram based upon the plurality of the sequential A/D conversions.

18. A fingerprint sensor according to claim **17** wherein said reference voltage determining and setting means comprises a processor, and at least one digital-to-analog converter connected between said processor and said at least one reference voltage input.

19. A fingerprint sensor according to claim **17** further comprising a respective amplifier cooperating with each A/D converter for permitting setting of the range thereof.

20. A fingerprint sensor according to claim **17** wherein said reference voltage determining and setting means comprises default setting means for setting at least one default reference voltage for initial ones of said fingerprint sensing elements.

21. A fingerprint sensor according to claim **17** further comprising a shield electrode associated with each electric field sensing electrode and connected to a respective amplifier.

22. A method for sensing fingerprints using an array of fingerprint sensing elements, each element comprising an electric field sensing electrode and an amplifier associated therewith, to enhance conversion resolution of ridges and valleys of the sensed fingerprints, the method comprising the steps of:

sequentially converting analog signals from predetermined ones of the array of fingerprint sensing elements to digital signals using at least one A/D converter having a controllable range; and determining and controlling the range of the at least one A/D converter based upon a plurality of the performed sequential A/D conversions performed by the at least one A/D converter to thereby provide enhanced conversion resolution of ridges and valleys of sensed fingerprints.

23. A method according to claim **22** wherein the range of the at least one A/D converter is controllable based upon at least one reference voltage; and wherein the step of determining and controlling the range comprises controlling the at least one reference voltage.

24. A method according to claim **22** wherein the step of converting analog signals comprises converting same using at least one amplifier having a controllable gain for permitting setting of the range; and wherein the step of determining and controlling the range comprises controlling the range using the amplifier.

25. A method according to claim **22** wherein the step of determining and controlling the range comprises generating a histogram based upon the plurality of sequential A/D conversions.

26. A method according to claim **22** wherein the step of determining and controlling the range comprises setting a default range for initial ones of the fingerprint sensing elements.

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